-*-*-*-*- Economics of Grade Reduction. -*-*-*-*-

A Study of the General Principles of the Economics to Be Effected By the Reduction of Grades, the Elimination of Rise and Fall and Curvature, and the Bettering of the Other Physical Conditions on the St. Louis & San Francisco Railroad Lines.

by

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Respectfully Submitted to the Faculty of the

UNIVERSITY OF KANSAS.

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Preface.

When railroad development first began, in the period between 1830 and 1835, the engines were so small and their tractive effort so little, that of necessity the grades must be kept to a minimum, and consequently we find the early railroads in England costing $300,000 per mile, while $200,000 per mile was not an uncommon figure in the United States. This excessive cost was not entirely due to the grading, however, thecost of iron materials being several times the cost today, and the type of construction was very expensive and as seen from the practice of today, extravagent.

The designs of locomotives changed so rapidly after 1835 that a design was almost obselete before it could be turned out of the shop. The development was so rapid that a suddent reversion from the level grade line railroad was the result, for it was found that the heavier engines could haul the business on heavier grades, and that the money for construction could more profitably be spent in building two or three miles of track than only one. This process of evolution continued until during the great railroading period of the eighties, when lines were being pushed into the wilderness in every direction, and cost must be kept as low as possible, an engineer would have been called rashly extravagant who would have laid a grade line such as might have been called the ultimate economical rate of grade. The result of this apparent original economy has been that today the volume of business on these railroads has become so great and the number of trains and the cost of operation so great, that many of the roads are actually losing money with the increase of business instead of making money. In order to permit the economical handling of this business it soon became evident that the grades must be reduced to permit of increasing the train or engine loads. In order to study the matter intelligently the first difficulty to be overcome was to find and separate into the proper units the cost of operating the railroads. The Interstate Commerce Commission fortunately came to the assistance of the engineer in 1906, and prescribed the manner in which railroad accounting should be done. It is true however, and a credit to the earlier investigators, that they had been able to arrive very closely at the cost of operation, even though the system of accounting was of very little value to them without a great deal of study.

Today engineers all over the world are studying the problem of the "Economics of Grade Revision," and the economies which may be effected in the operation of the railroads by the elimination of the heavy existing grades, the elimination of the rise and fall and curvature, and the bettering of the other physical characteristics of the roads, in order to increase the net revenues. The work is no longer haphazard, but is conducted on well established theories, and with practically no doubt as to the results.

This report deals particularly with the conditions on the St. Louis and San Francisco Railroad and its allied lines. The problem is studied, not in reference to any particular part of this road, but to its conditions in general, and attempts to show the underlying principles which must be followed in the study of the reduction of grades on this particular railroad. The same principles are true of other lines of railroad, and with the modifications suggested in various parts of the volume may be made to apply to other lines as well. The mechanical data given has particular reference to the Frisco Lines and such similar information must be worked out for each railroad before an intelligent study can be made of the reduction of its grades, etc.

This report was written in the year 1912, and no changes have been considered necessary to date. Some progress has perhaps been made in the determination of train resistance formulae as applied to the making up of trains in hot and cold weather, and with other physical conditions, but these have very little bearing on the general results.

The method of railroad accounting will probably be changed by the Interstate Commerce Commission during the year 1914, and it remains to be seen whether the result will be of benefit or otherwise to the study of this important question.

Feb. 10, 1914.
St. Louis, Mo.

P. J. Neff.

MAP OF
FRISCO LINES
AND CONNECTIONS

CONTENTS.

INDEX--Continued.

INDEX-COntinued.

INDEX-Continued.

T A B L E S .

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Springfield, Mo., June 1st., 1912.

Mr. M. C. Byers,

Chief Engineer-Operation Frisco Lines,

Springfield, Mo.

Dear Sir:-

In the latter part of the fiscal year 1910-1911 I received instructions from you to make a study of the existing grades on the Frisco Lines of railroad and to prepare a report on the "Economics of Grade Reductions" as particularly affecting the Frisco Lines. This report was to cover the general theories of the economy to be derived from reduction of grades, changes in distance, and increases or decreases in the total rise and fall. Your instructions were further, to prepare such figures in reference to tonnage rating, train resistance, grade resistance, curve resistance, and velocity grades, as would be necessary in solving grade reduction problems on various portions of the railroad as they might arise.

In accordance with those instructions, I beg to submit the attached report. In preparing the information which is given, I received valuable assistance and hearty co-operation of the various departments of our railroad, especially from the Mechanical Department, as well as from the following publications by well known writers on the question in hand:-

Mr. A. C. Dennis-"Virtual Grades for Freight Trains." Bulletin A. S. C. E. #942.

Mr. W. W. Colpitts-"Economics of Railway Improvements." Canadian Society of Civil Engineers, Bull. #160.

Mr. W. G. Curtis and committee appointed by Mr. Julius Kruttschmitt, General Manager of the Southern Pacific Railway System-"Locomotive Tonnage Rating." Published as Vol. XI, No. I, of Amer. Railway Eng. & Maint. of Way Association.

Mr. J. B. Berry-"Reduction of Gradient and Elimination of Distance, Curvature, and Rise And Fall on Union Pacific Railroad." Published as Bulletin No. 49, A. R. E. & M. of W. Association.

Mr. J. B. Berry-and various members of the American Railway Engineering Association.-"Discussion of Bulletin No. 49, by Mr. J. B. Berry." Published as Bulletin No. 52, Amer. Ry. Eng. & Maint. of Way Association.

Prof. W. D. Pence-"The Construction of Diagrams for velocity Grades." Proceedings of the Purdue Society of Civil Engineering, 1904 Proceedings, Vol.#8.

Mr. C. D. Purdon-"Reduction of Grades on Railroads." Paper read before A. S. C. E. 1906. Not published.

Mr. W. McNab and special committee of A. R. E. A.-"Economics of Grade Reduction." Paper dealing principally with train resistance. Published as Bulletin #84 of A. R. E. A.

Mr. A. M. Wellington-Book-"Railway Location."

Mr. G. R. Henderson-Book-"Locomotive Operation."

Prof. W. L. Webb-Book-"Economics of Railroad Construction.

Mr. Edward C. Schmidt-"Freight Train Resistance." Published as University of Illinois Bulletin #43.

Prof. W. G. Raymond-Book-"Elements of Railroad Engineering."

American Locomotive Co.-Bulletins #1001 and #1002.

Annual Reports of the Frisco Lines for a number of Years.

Further information of much value was found in discussions of the subject printed in the Proceedings of the American Railway Engineering and Maintenance of Way Association, and American Society Of Civil Engineers, and in numerous discussions and papers printed in the technical journals. While these papers printed in the technical journals contained valuable information they are rather toonumerous to list.

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After making a general study of the subject and reviewing all the information at hand, the question of the Economics of Grade Reduction naturally divides itself into two general heads:-

1.-A study of the financial value of the physical characteristics of a railroad.

2.-A study of the mechanical performance of engines and equipment.

The first general head further resolves itself into the following general sub-heads:-

A,-The financial value of increasing or decreasing the train mileage necessary to handle a given traffic, or the increase or decrease to operating expenses coincident with any changes in the ruling gradients.

B.-The financial value of distance, or the increase or decrease to operating expenses coincident with any changes in the total length of track. This sub-head may be further divided as follows:-

b_1.-Changes in the total distance not great enough to affect train wages or wages of enginemen.

b_2.-Changes in distance great enough to affect train wages, but not great enough to require additional side tracks or stations.

b_3.-Changes in total distance great enough to affect wages of trainmen and enginemen and to require additional side tracks or stations.

C.-The financial value of rise and fall, or the increase or decrease to operating expenses coincident with changes in minor grades, or grades less than the ruling gradient and which do not change the engine ratings or the total train mileage. This sub-head may be further divided as follows:-

c_1.-Small undulations in grade not affecting the amount of steam used.

c_2.-Grades which require the partial or total shutting off of steam in the descent, but which require the full power of the engine in the ascent.

c_3.-Grades which require the shutting offof steam and use of brakes in the descent and the full power of the engine in the ascent.

D.-The cost of helper grades, or a study of the increase or decrease to operating expenses coincident with the use of helper engines on any portion of a division to handle a given tonnage, as compared to the interest charges on the capital necessary to reduce such helper grade to the otherwise ruling gradient.

E.-The financial value of curvature, or the increase or decrease to operating expenses coincident with any changes in the total curvature.

The second general head developed into a problem of determining what the total train mileage should be on an existing railroad as compared to that which should be obtained after any changes in the physical characteristics of the railroad. In working up the report the important questions which presented themselves were as follows:-

A.-Locomotive tractive power, or a study of the draw bar pull which a locomotive will exert on any gradient and at any speed.

B.-Train resistance, or a study of the following resistances to be overcome in hauling a train at any desired speed over any given track.

b_1.-The resistance to uniform motion along a straight level track to be overcome in hauling a car of any given weight at different speeds.

b_2.-The resistance to be overcome due to gradient.

b_3.-The resistance to be overcome due to curvature.

b_4.-The resistance to be overcome in accelerating speed.

C.-Velocity or momentum grades, being a study of the acceleration or retardation of trains on various grades, due to the acquisition or giving up of potential energy.

In the body of the report each of these points are discussed and conclusions drawn. Wherever possible the figures were made applicable to the conditions on the Frisco Lines in order that they might be of use in our own problems.

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After determining what constitutes the main features of the subject, a logical method of application to any existing problem must be worked out. In order to do this the broad general principle of the economy of a grade reduction should first be laid down. As a railroad is built and operated with the expectation of earning a reasonable profit over and above the interest charges which must bepaid on the capital invested, we may summarize the value of a grade reduction by saying it is profitable or not depending on whether the net revenue after the reduction becomes greater or less than it was previous to the reduction. Or, expressed in slightly different terms, it must be shown that the increased interest charges made necessary by the increased capital required for the grade reduction, will be less than the saving in operating expenses. If the saving in operating expenses is greater than the increased interest charges the reduction of grades is evidently economical, and the problem develops into one of securing the necessary capital and carrying out the work.

It does not seem possible to lay down a definite line of procedure to be followed in all cases of estimating the relative economy of two lines, due to the great variety of operating conditions. Before considering the minor savings which may be made by reductions of distance, curvature, etc., there must be determined as nearly as possible the saving which may be effected in the total train mileage by any reduction in the ruling gradients. In order to do this, a general study of the operating conditions of the division affected must be made in order to determine the various classes of freight handled and the various ways in which it may be moved. To simply say there are so many tons to be moved each day or each month and calculate the number of trains necessary to handle this tonnage will lead to erroneous results, and this has too often been done. The amount of each class of business offered will evidently become the first vital point to be determined. We cannot move coal in merchandise trains any more than we can afford to move local freight in passenger trains. But if we find we are running two merchandise trains each day where one would suffice with a reduction of ruling gradient and corresponding increase in rating, or if we are running a drag freight every day where one every two days would suffice with a reduction in the ruling gradient, it is at once evident that an economy may develop from the reduction of the ruling gradient. On the other hand, we may find that the merchandise offered is only sufficient to fill out one daily train of that class, as rated on the existing grades, and that as such merchandise must move daily there would be no material saving possible from a reduction of grades as affecting that class of commodity, as the train load could not be increased. These facts make it imperative to first determine as nearly as may be, the method of handling each class of freight, and then to determine for the division as a whole the probable saving in train mileage. If the estimated saving in train mileage appears to be sufficient to warrant a survey or detailed estimate of the cost of the grade reduction, such figures may be worked up and the minor savings in distance, rise and fall, and curvature , taken into the calculations. It is of course possible that the minor changes may show an increase to the cost of operation instead of a decrease, and the net result of the changes will have to be determined.

RATE OF GRADE:-The question of the maximum rate of grade and the ruling grade to be adopted will depend largely on the physical characteristics of the remainder of the railroad. As shown in the body of the report, there is seldom any economy to be derived in operation by reducing below a four-tenths of one per cent grade. But shall a six-tenths or a one per cent be adopted?. Only an estimate as to the cost of reducing to both the six-tenths and to the one per cent will show. Either one may be cheaper than the other depending entirely on the cost of the work and the saving in train mileage. Good judgment on the part of the engineer and familiarity with the territory will usually narrow the limits to one or two possible cases. In establishing the rate of ruling grade due care must be exercised and due consideration given to the probable increase in traffic, as any reduction in gradient involves large operating expenses,* which should be absorbed by reductions in operating expenses before any future reductions in grade should be necessary. For this reason it may be advisable to adopt a ruling grade less than the most economical present rate of ruling grade would be. But the only practical way to make the decision, is first to determine the cost of each reduction and the probable saving to be effected. If it develops that the six-tenths per cent grade can be obtained at a profit and the expectation of a large increase in traffic seems justifiable, there would seem to be very little question as to the advisability of adopting the lighter grade, and yet the difference in interest charges as between obtaining a six-tenths per cent and a one per cent grade may be more than the estimated saving between the two grades even though both may show a probable reduction in operating expenses greater than the increased interest charges in either case.

* Note:-Reference to classification of the Interstate Commerce Commission "Classification for Expenditures for Additions and Betterments," will show that a large part of the cost of any grade reduction, or possibly all of the cost may be chargeable to operating expense, and is payable from the regular operating revenues of the road.

Before it can be known what saving in train mileage is to be effected by a reduction of gradient, there must first be determined the train loads which can be handled on the existing grades with the engines which are assigned to that particular division. This may be done on our particular railroad by selecting from Table VII the draw bar pull for the engines specified and dividing it by the total resistance per car of the kind of train considered. From the same table and the total resistance on other grades, determined from the information in the body of the report, there may be found the train load on such other grade as is being considered. One important point should be remembered in this connection, viz.; the calculated train load may not in either case be exactly what experience will show can be handled on the grades considered, nor will the calcu-lated train load necessarily be that which any particular engine is actually handling. But the only error of moment in such case will be in the estimated saving in train mileage, for the same degree of efficiency or inefficiency is to be expected after the reduction of grade as before. As the estimated saving per train mile as given in the report is made up very conservatively it is believed no material error will result.

For convenience there is given on the following page a tabulation showing the per cent of trains necessary to handle a given traffic with a single engine, if the grades are changed from one grade to any other grade. This table is a reprint of table No. 7 in Mr. J. B. Berry's report on reduction of grades on the Union Pacific R.R. In calculating the table, 6-lbs. per ton was assumed as the average train

GRADIENTS ARE CHANGED FROM THOSE IN FIRST COLUMN TO ANY OTHER GIVEN GRADIENT. MAXIMUM MAINTAINED SPEED TEN MILES PER HOUR.– REPRINT OF TABLE BY MR. J. B. BERRY. BULL. #49-A.R.E. ASSOCIATION.

GRADIENT TO BE REDUCED %	PROPOSED GRADIENT, PER CENT, WITH PER CENT OF TRAINS TO HANDLE SAME TRAFFIC AS ON ORIGINAL GRADIENT.															
	+0.4	+0.5	+0.6	+0.7	+0.8	+0.9	+1.0	+1.1	+1.2	+1.3	+1.4	+1.5	+1.6	+1.7	+1.8	+1.9	+2.0
+2.0	26	30	34	38	42	46	51	55	60	65	69	74	79	84	89	95	100
+1.9	27	31	36	40	44	49	54	58	63	68	73	78	84	89	95	100	
+1.8	29	33	38	42	47	52	57	62	67	72	78	83	89	94	100		
+1.7	31	35	40	45	50	55	60	66	71	77	82	88	94	100			
+1.6	33	37	43	48	53	59	64	70	76	82	88	94	100				
+1.5	35	40	46	51	57	63	68	75	81	87	93	100					
+1.6	37	43	49	55	61	67	73	80	87	93	100						
+1.3	40	46	53	59	66	72	79	86	93	100							
+1.2	43	50	57	64	71	78	85	92	100								
+1.1	47	54	61	69	76	84	92	100									
+1.0	51	59	67	75	83	91	100										
+0.9	55	64	73	82	91	100											
+0.8	61	71	80	90	100												
+0.7	68	79	89	100													
+0.6	76	88	100														
+0.5	87	100															
+0.4	100																

resistance on level tangent, the same as recommended in this report for a comparison of the relative number of trains necessary to handle a given traffic on different grades. This figure will be used only in the preliminary investigation however. In the detailed analysis the resistance of cars of the various kinds under consideration.

After completing the investigation of the handling of trains, the next step will be a theoretical summation of the train loads which should be handled over the existing grades with the engines assigned to the territory. This will be followed with an investigation as to the train loads these same engines should handle upon different reductions in the ruling gradients, always bearing in mind the manner in which the freight must be moved. An estimate covering the cost of the various reductions and the minor savings or increases to operating expenses will show whether any reduction is advisable and which, if any is the most economical.

A study of the profile with the figures given in tables VIII and IX will show what grades may be operated on the velocity or momentum principal with any reduction in the ruling gradient. It will occasionally be necessary to study the movements of an engine with less than its rated tonnage, in connection with the velocity grade problem. The most satisfactory way to handle this is to reduce the excess tractive power of the engine, over and above that necessary to maintain the minimum speed on the ruling rate of grade, to pounds per ton of train actually handled, and add the same to the various grades on the profile. In this manner the decrease in CYLINDER tractive power of the engine with increase in speed is taken care of without any further calculations.

The more important formulae and the values determined for any changes in distance, rise and fall, and curvature, etc., are given below, such values being based on the actual cost of operation as given in the 1910-1911 annual report, and being an average of the entire system. The important formulae entering into the mechanical side of the problem are also given.

1.-Saving per freight train mile coincident with any decrease in total train mileage in handling a given traffic, due to a reduction in the ruling gradients;

39.7% of \$1.58 or \$0.627 per train mile.

In order to effect this saving, it will be necessary that a train mile saved in one direction be also saved in the opposite direction, as the power must be kept equalized.

2.-Saving per passenger train mile coincident with any decrease in total train mileage, in handling a given traffic, due to a reduction in the ruling gradient.

44.4% of \$0.90 or \$0.40 per train mile.

*Note:-This saving will seldom be made, as there will be but few cases where any reduction in the ruling gradient will affect the passenger train mileage.

3.-The cost per annum of increasing the freight train distance, for each daily train.

a.-Each foot of distance where total change in distançe is not great enough to affect the wages of trainmen or enginemen ------------------$0.028

b.-Each mile of distance where total change in distance is great enough to affect the trainmen's wages, but not great enough to require additional side tracks or stations-$243.37

c.-Each mile of distance where total change in distance is great enough to affect the trainmen's wages, and to require additional side tracks and stations -------------$318.50

4.-The cost per annum of increasing the passenger train distance, for each daily train:

a.-Each foot of distance where total change in distance is not great enough to affect the wages of trainmen or enginemen -----------------$0.018

b.-Each mile of distance where total change in distance is great enough to affect the trainmen's wages, but not great enough to require additional side tracks or stations --$117.89

c.-Each mile of distance where total change in distance is great enough to affect the trainmen's wages and to require additional side tracks and stations ------------$159.00

5.-Effect on operating expenses of increasing the total rise and fall:

a.-Increased or decreased cost per foot of rise and fall on grades requiring the partial or total shutting off of steam in the descent and full power of the engine in the ascent --$0.0029

b.-Increased or decreased cost per foot of rise and fall on grades which require the shutting off of steam and the use of brakes on the descent, and the full power of the engine in the ascent ------------------$0.0037

6.—Helper engine service for one day and night helper increases the cost per train mile $0.36, provided the helper engine makes at least 100 miles on each shift of 12 hours. In most cases which will come under consideration on existing lines, it will be possible to get accurate figures as to the actual cost of the helper service, and the figure of $0.36 per train mile should be used only for estimating purposes in considering the increasing of the train load on a portion of some division by using a helper engine on the otherwise ruling gradient. Instead of the figure of $0.36 per train mile, $22,000 per year per one day and night helper engine should be used where the total daily mileage of helper engine is likely to be less than 100 miles per 12 hour shift, this figure will also include interest and depreciation on the ordinary type of helper engine.

7.—Effect on operating expenses of increasing or decreasing the total degrees of curvature. Value of one degree of curvature per daily train per year -------------------------------- $0.30

8.—Formulae for determining the draw bar pull of simple and compound locomotives at any speed and on any grade:-

a.—Draw-bar pull of simple locomotives.

$$D.B.P. = \frac{d^2 sKF85}{D} - (x + x_1 + x_2 + 22.2T + .3V^2 + 20RgW)$$

D. B. P.=Draw bar pull in pounds.
d =Diameter of cylinder in inches.
s =Piston stroke in inches.
K =Multiple of 100# boiler pressure.
F =Speed factor taken from table IV.
D =Diam. driving wheels in inches.
x =Total lbs. resistance in engine trucks.
x_1=Total pounds resistance in trailer.
x_2=Total resistance in tender with full supply of water and coal.
T =Total weight in tons of 2000# on driving wheels.
V =Speed in miles per hour.
Rg=Rate of grade.
W =Total weight in tons of 2000# of engine and loaded tender.

b.-Draw bar pull of two cylinder compound locomotives.

$$D.B.P. = \left(\frac{C^2sRP}{2D} + \frac{c^2sR_1P}{2D}\right) - (x+x_1+x_2+22.2T+.3V^2+20RgW)$$

c.-Draw bar pull of four cylinder compound locomotives:-

$$D.B.P. = \left(\frac{C^2sRP}{2D} + \frac{c^2sR_1P}{2D}\right) - (x+x_1+x_2+22.2T+.3V^2+20RgW)$$

In the equations for the two and four cylinder compounds the following abbreviations are used:-

C= diameter in inches of high pressure cylinder.

c= diameter in inches of low pressure cylinder.

P= boiler pressure.

R_1= ratio of mean effective pressure to boiler pressure in low pressure cylinder, taken from Fig. E.

R = same ratio for high pressure cylinder.

Remaining factors same as in simple locomotives.

9.---Formula for tonnage rating of any engine on any grade and at any desired speed, and hauling cars of a given average weight:-

$$T = \frac{D.B.P.}{R+Rg}, \text{ where}$$

T = Total weight of train in tons back of tender.

D.B.P.= Draw bar pull of locomotive, selected from table VII.

R = Train resistance per ton for the average weight of cars, selected from table I

Rg= Resistance due to grade, and equal to 20 pounds per ton for each 1.00% of grade.

Note---The factor Rg and the factor D.B.P. must be corrected for curvature if such exists. Proper compensation may be taken from Table II.

10.--Formulae for train resistance, being resistance to uniform motion along a straight level track of cars of given average weights and at any desired speed. Resistance to be expressed in pounds per ton.

When	$W = 15$ T;	$R = 7.15 + 0.085\ S + 0.00175\ S^2$
"	$W = 20$ T;	$R = 6.30 + 0.087\ S + 0.00126\ S^2$
"	$W = 25$ T;	$R = 5.60 + 0.077\ S + 0.00116\ S^2$
"	$W = 30$ T;	$R = 5.02 + 0.066\ S + 0.00116\ S^2$
"	$W = 35$ T;	$R = 4.49 + 0.060\ S + 0.00108\ S^2$
"	$W = 40$ T;	$R = 4.15 + 0.041\ S + 0.00134\ S^2$
"	$W = 45$ T;	$R = 3.82 + 0.031\ S + 0.00140\ S^2$
"	$W = 50$ T;	$R = 3.56 + 0.024\ S + 0.00140\ S^2$
"	$W = 55$ T;	$R = 3.38 + 0.016\ S + 0.00142\ S^2$
"	$W = 60$ T;	$R = 3.19 + 0.016\ S + 0.00132\ S^2$
"	$W = 65$ T;	$R = 3.06 + 0.014\ S + 0.00130\ S^2$
"	$W = 70$ T;	$R = 2.92 + 0.021\ S + 0.00111\ S^2$
"	$W = 75$ T;	$R = 2.87 + 0.019\ S + 0.00113\ S^2$

A tabulated statement of the resistance for different average weights of cars at speeds ranging from 5 to 40 miles per hour is given in report as Table I. The formulae and table are reprints from Bulletin #43 of the Illinois Experiment Station, and were compiled by Prof. Edward C, Schmidt from tests on the Illinois Central Railroad. They are indicative of train resistance during ordinary weather conditions only. I believe that while experiment has shown conclusively that train resistances increase in cold weather, the question of this increase has little value in a report dealing with grade reduction. It is considered better, from a practical standpoint, to analyze the actual engine performance on the division in question and then to assume that after the grade reduction, the per cent of rating handled will be the same as before the reduction.

11.--Formula for the resistance due to grade.

This is purely a mathematical determination and the formula is:-

$R = 20\ Rg$, as sometimes expressed, the resistance due to grade is 20 pounds per ton for each 1.00% of grade. The error in this calculation is about .02 of one per cent on a two per cent grade, a quantity which is negligible.

12.-Formula for resistance due to curvature.

The resistance due to curvature has been experimentally determined as averaging about 0.8 pounds per ton per degree on curve, equivalent to a .04 per cent grade. While this figure may not be correct under all conditions, due to physical characteristics of different pieces of track, and the class of maintenance, it represents about the average maximum, and may be used in all cases with little error. It is considered better to give too much correction for curvature than too little, especially as the tendency is always to increase the rate of grade on curved track by increasing the depth of ballast. This is especially noticeable on curves at summits.

13.-Formula for calculating force required for a given acceleration of speed in a given distance:-

$$P = 70\,\frac{W}{l}(S_2^2 - S_1^2), \text{ where}$$

P = Total acceleration force in pounds.
W = Weight of train in tons.
l = Distance in feet.
S_2 = Final Speed required.
S_1 = Initial speed.

14.-Formula for calculating distance required to increase velocity a given amount with a given accelerating force:-

$$l = 70\,\frac{W}{P}\,(S_2^2 - S_1^2)$$

Factors same as in above formula.

A more accurate determination may be made by calculating the distances required to increase the velocity by one mile per hour increments, the total of the increments givivg the required distance. The formula then becomes--

$$l = 70\,\frac{W}{P}\,(\ 2S_1 + 1\ )$$

15.-Formula for determining how great a load can be carried if it is desired to increase the speed in a given distance with a given accelerating force:-

$$W = \frac{P\ l}{70\ (S_2^2 - S_1^2)}$$

Factors are the same as in (13)

16.-Formula for velocity head.

$$h = .035\ S^2$$

where h = height in feet which a train will be lifted, solely by its potential energy, at a speed of S miles per hour. This formula does not consider the train resistance, etc., hence is useful only in connection with other formulae. Its principal value lies in its interchangeability with speed in the study of grades operated on the velocity or momentum principle.

Reference is made to the body of the report for the derivation of the various formulae, and their principal uses in the study of grade reduction problems.

Very respectfully yours,

P. J. Neff

Assistant Engineer.
Springfield, Mo.

Discussion of the Financial Values to Be Determined Preparatory to An Estimate of the Economy of Any Grade Reduction, and the Estimated Cost Per Train Mile of An Additional Train to Handle A Given Traffic.

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The question of grade reduction fundamentally depends upon whether the net revenue after the grade reduction is increased. Expressed in slightly different terms, to be an economical move, it must be shown that the interest charges on the capital invested, which include the original cost as well as the betterment cost, and also the maintenance cost, or charges to operation, will be less than the saving in operating charges after such grade reduction. It is presumed that the engineers and railroad builders of twenty to forty years ago made the same preliminary study of the location of their lines, as is ordinarily employed today. The necessity of a railroad became recognized or the possibilities of development realized. The question was studied as thoroughly as possible to determine the amount of revenue which could be derived from the construction of such a railroad. If the anticipated profits were great enough to warrant further investigation the subject was then gone into from an engineering standpoint, and an estimate made of the cost of constructing the line and the probable expense of operation.

In locating his line the engineer was usually limited to such amount of money for construction as would reasonably assure a profit to the share-holders after paying the interest on the capital invested and the operating expenses of the railroad. Within reasonable limits no attempt was made to secure a grade line lower than the character of the country traversed would warrant, with the natural result that after many years of operation, with many times the business originally offered, the question of decreasing the train mileage by securing a lower grade line becomes pertinent.

Of course many lines of railroad have been built which were not expected to be a paying investment in themselves, but which were constructed to divert traffic to the main lines, or to increase the value of property. Many of these lines have later formed portion of trunk lines, with the result that their original profiles need revision for more economical operation.

These reasons and many others have often caused the construction of railroads on grade lines which would not be considered economical or profitable today. The amount of money available probably had considerable to do with the character of construction of many of the lines, the promoters being forced to accept less profits because the necessary capital could not be obtained.

Since the original line was built traffic has increased, until in some cases any increase in business may actually decrease the net revenue on account of blocading the road. In consequence the length of trains must be increased by increasing the size or tractive power of the locomotives, by reducing the ruling gradients or by building double track. In the latter case the reduction of grades is ordinarily carried on simultaneously unless the second track be located on an entirely new location.

With the economical substructure of our tracks of today, with the weight of rail employed, etc., it has been all but universally conceded that we cannot very materially increase the weight of locomotives on their drivers. Neither will the present construction of equipment stand much increased strain, which would be put upon it by increasing the tractive power of the locomotives. For these reasons, while it is conceded that some further progress will be made along these lines, it is certain that we cannot expect any very great savings to result, owing to the consequent increased maintenance charges, coincident with any increase in the wheel loads of motive power and equipment.

Reduction of the ruling gradients of the existing line permits of a greater tonnage per train, or a larger engine rating, and thus by decreasing the train mileage saving a portion of the cost of handling the business, or in event of increased business, by keeping the number of trains the same, permits of the increased business being handled at a profit.

Double track, as a solution to the economical handling of freight, should as a rule not be attempted until the single track line has been made to handle the greatest amount of traffic possible, and double track work will not then be profitable until as in the case of grade reduction, the interest charges are less than the saving in operating expenses. Actually, however, we may find that it will be necessary to double track in order to handle the tonnage offered, even though for a period of years the net profits will be considerably less than the net profits of the single track line handling its maximum tonnage.

Ordinarily the reduction of grade of a single track line is preliminary to double track work. When such is the case due consideration should be given the question of direction of traffic on the double track line, as it will occasionally be found that the second track may be located off the right of way of the first, and secure the advantage of a descending grade in the heavy traffic direction, using the old line for the lighter traffic, and often eliminating to a large extent the necessity of revision of the grades on the old line. This may make it desirable to reduce only those grades on the single track line opposing traffic as it will finally be. Field investigations are of course necessary to determine whether or not such a plan may be worked out.

Items Affecting Operating Expenses;- The main items affecting operating expenses so far as location of a line is concerned, are DISTANCE, RISE AND FALL, CURVATURE and the GRADIENTS. The values of these items, in so far as their connection with the reduction of grades on existing lines of railroad is concerned, must be determined from the cost of operation of each distinct railroad, or portion of railroad affected, and no general value can be derived to fit all conditions. The uniform system of accounting prescribed by the Interstate Commerce Commission in 1907 has simplified the problem very materially, as we can now separate the cost of maintenance and operation very readily into the portions affected by train mileage and the portions unaffected by train mileage.

On preliminary locations, it becomes necessary to estimate the value of distance, in order to determine whether interest on increased cost of construction for a shorter or longer route will be offset by the returns anticipated, either from a reduction in operating expenses or an increase in gross revenue. The cost of carrying over a greater distance all the traffic may be more than the net revenue derived from some locality which made the greater distance necessary. However, these features more properly belong to the scope of the locating engineer and the builder of the original line than to the engineer studying grade revision, except as distance will affect such short changes of line as may be contemplated in the reduction of grades. Changed of distance or in located lines for the purpose of increasing the gross revenues, should be made the subject of a special study. Usually it will be found that the line after reconstruction is shorter than before, and it would seem that unless a great amount of saving was to be made in distance, no change of line would be justifiable with that sole end in view. The best practice then would be to determine the total distance gained or lost after the study of the problem as a whole. The calculated value of distance may then be applied, and the estimated total taken into the final calculations.

The relation of rise and fall and gradients in general is closely associated with that of operating expenses, and may be determined with sufficient accuracy to give reliable values to each of the items. Rise and fall should be considered only in reference to minor grades, or those on which the tonnage is moved at approximately the mazimum speed. The direct charges to this account are a slightly increased wear and tear on equipment, a larger number of foot pounds of energy which are required to lift the train over the elevation, and a corresponding increase in fuel consumption. However, there are also some advantages outside of the saving in the cost of construction. These advantages are principally confined to allowing opportunity for the locomotive to maintain the proper boiler pressure, for we know, strange as it may seem that every locomotive will lose head of steam in running for many miles over level track, while the slight ascents and descents allow of working the maximum and then taking a breathing spell, so to speak.

Prof. Webb, in his treatise on the economics of railroad construction, discusses the subject at considerable length, and says, in part:-

"The disadvantages of such rise and fall are always largely compensated. Except for the fact that one terminus of a road may be higher than the other, every up grade is followed more or less closely by a lower grade, which is operated by the potential energy required during the previous climb. But when we consider the train's running in both directions, even the difference of elevation of the termini is largely neutralized. If we could eliminate altogether the waste of energy in the use of the brakes, where brakes are used to control the train on grades, we would then find that the net effect of minor grades on either operation in both directions would be zero.* Whatever was lost on any up grade would be regained on the succeeding down grade or on the return trip. On the very lowest grades, we may consider this to be literally true, viz-that nothing is lost by reason of their presence. It is unnecessary to use brakes on these grades, except for such use as would be made if the line were level. Whatever energy is temporarily lost in climbing any grade is either immediately regained on a subsequent down grade or is regained on the return trip."

* Note-Prof. Webb's statement may possibly not

take full recognition of the fact that there are very few lines on which the tonnage is balanced, and in cases where the difference in elevation of the termini is large, and the direction of maximum traffic toward the ascent, the effect of traffic being in two directions would not tend to balance the effect of minor grades to any great extent, as the minor traffic would be hauled in trains far below the full rating of the engine on the majority of the minor grades.

THE RULING GRADIENT is the most important item which the engineer has to consider in relation to operating expenses. The minor ascents and descents just considered are always below the ruling gradient, hence do not affect the engine rating or the train mileage, except in the aggregate. But upon the ruling gradient depends directly the number of trains which will have to be operated to carry the traffic. Hence the cost of operating the line will depend on the maximum, or ruling gradient, not so much by increasing the cost per train mile as by limiting the number of cars which may be hauled in one train. Thus a line of ordinarily low grades may be made a line of high cost of operation because of one or two heavy grades. The question then, of reducing such grades in order that the traffic may be carried in fewer trains is the most important question with which we have to deal.

The last item, of curvature, is also an important one,as curvature increases the total resistance which the engine must overcome in hauling the train, and causes increased cost in operating expenses covered by the maintenance of equipment, due to wear on flanges, strains, and to maintenance of track due to excessive wear on rails, unequal strains on roadbed, etc.

The FINANCIAL PROBLEM then in grade reduction investigation, is first to determine in dollars and cents, the value of eliminating one unit of distance, one unit of curvature, one unit of rise and fall, and most important of all the value of decreasing the train mileage by increasing the tonnage rating,by reason of a reduction in the ruling gradient. As the train mile is the unit of expenditure in considersation of operating expenses, there must be determined the saving in train miles, by decreasing the distance, the curvature and the gradients. If the saving in operating expenses by reducing the number of train miles to handle a given traffic is more than the interest at the prevailing rate on the money necessary to carry out the work, the expense of the grade reduction is justified. If the saving is about the same as the interset, the grade reduction will still be justified in anticipation of greater business in the future, unless the conditions of the money market are such that it may be reasonably anticipated that the interest rate will be decreased before any great increase in business arrives.

In determining the various financial values above mentioned as applicable to the Frisco Lines, we will use the Annual Report for the fiscal year ending June 30, 1910, this being the last annual report available at the present time. The report shows in an itemized statement made in accordance with the classification of the Interstate Commerce Commission, the total operating expenses, the total train mileage, and other data necessary for working out the information desired. First will be determined the saving to be effected by reducing the total number of train miles.

Below is given a statement of the operating expenses for the fiscal year ending June 30, 1910, with the per cent each item bears to the whole:-

Maintenance of Way and Structures.

	Amount	% of whole.
Superintendence,	$ 367,540.13	% 1.22
Ballast,	50,363.01	.17
Ties,	1,339,575.39	4.44
Rails,	151,511.73	.52
Other track material,	252,552.36	.84
Roadway and track,	1,930,541.74	6.41
Removal of snow, sand, etc	16,332.79	.05
Tunnels,	69.08	.00
BR, trestles & culverts	864,825.58	2.87
Over & under grade Xings	4,463.45	.02
Fences, cat. gd. & signs	126,041.21	.42
Snow & sand fences, etc	23.48	.00
Signals & interlocking	56,915.27	.19
Tel. & telephone lines	113,051.61	.38
Bldgs, fixt, & grounds	417,039.61	1.38
Roadway tools & supplies	99,244.13	.33
Injuries to persons	28,649.25	.09
Stationery & printing,	14,344.12	.06
Other expenses,	1,594.68	.01
Maint. joint tr.-Dr)		
" " " -Cr) Bal.	Cr.55,833.47	.19
TOTAL	$5,778,268.15	19.21

Maintenance of Equipment.

	Amount	% of whole.
Superintendence,	$ 157,279.48	.52
Rep-Renew-Dep of Loco-	3,030,575.03	10.05
" " " " Pass-Cars	465,866.90	1.54
" " " " Frt-Cars	2,018,268.73	6.70
" " " " Work Equip-	71,797.63	.24
Shop machinery & tools	158,013.51	.53
Injuries to persons	36,330.23	.12
Stationery & printing	12,162.66	.04
Other expenses	286,70	.00
Maint joint equip- Cr.	10,270.50	.03
Total------------	$5,940,310.37	19.71

Traffic) Expense.

Superintendence,	246,274.14	.82
Outside agencies,	390,481.91	1.31
Advertising	169,645.68	.56
Traffic Associations	23,284.71	.07
Ind. & Immigration Bureau	32,109.55	.11
Stationery & printing,	170,766.32	.59
Other expenses,	4,258.92	.01
Total------------	$1,036,821.23	3.47

Transportation Expenses.

Superintendence,	397,460.57	1.32
Dispatching trains,	193,756.77	.64
Station employes,	1,839,230.37	6.10
Weighing & car ser. as-	56,806.45	.18
Station supplies & exp	134,028.25	.44
Yard masters & clerks	220,762.76	.73
Yard Con. & Brakemen	653,442.20	2.17
Yard Sw. & Sig. Tenders	17,003.61	.07
Yard supplies & exp.	10,441.52	.03
Yard enginemen,	371,071.17	1.23
Engine house expenses,	116,646.51	.39
Fuel for yard locomo-	337,929.90	1.12
Water for yard locomo-	22,679.93	.07
Lubricant for yd. loco-	9,614.11	.04
Other sup. for yd. loco-	8,159.78	.04
Oper. Jt. yds. & Ter.-Dr.	225,783.78	.76
" " " " " -Cr.	189,687.81	.62
Road enginemen,	2,057,887.64	6.84
Enginehouse exp-Road,	417,809.46	1.40
Fuel for road locomo-	2,963,171.66	9.80

Transportation Expenses.-Continued.

	Amount.	% of whole.
Water for road loco-	$ 207,218.64	.70
Lubr- for road loco-	74,689.42	.24
Oth.suppl-road loco-	64,643.39	.21
Road trainmen,	2,211,486.03	7.34
Tr. suppl & Expenses,	553,945.43	1.85
Operation-Interlockers,	49,170.62	.16
Crossing Flagmen-Gatemen	54,593.56	.18
Drawbridge operation,	1,785.98	.01
Clearing wrecks,	123,364.40	.40
Telegraph & Telephone	82,442.36	.27
Stationery & Printing,	123,992.02	.41
Other ezpenses,	19,443.28	.06
Loss & Damage-Freight,	549,974.30	1.63
" " " -Baggage,	25,799.61	.09
Damage to property,	180,130.58	.60
Damage to stock on R/W	165,047.88	.54
Injuries to persons,	371,100.76	1.23
Operation Jt. Tracks-Dr.	68,644.60	.24
" " " -Cr.	93,377.11	.30
Total---------	$14,698,094,38	48.81

General Expenses.

Salaries and expenses, General Officers------	$ 209,726.33	.70
Salaries and expenses, Clerks and Attendants,	412,220.57	1.37
General Office supplies and expenses,---------	70,091.03	.23
Law Expenses,	223,010.30	.74
Insurance,	172,301.69	.57
Stationery and printing	72,961.07	.24
Other expenses,	69,622.93	.23
Gen. administration joint Facilities.-Dr.	5,683.79	.02
Gen. administration joint Facilities.-Cr.	12,269.65	.04
Total--------	$ 1,223,348.06	4.06

RECAPITULATION.

	Amount	% of whole.
M. of Way and Structures,	$ 5,778,268.15	19.21
Maintenance of Equipment,	5,940,310.37	19.71
Traffic Expenses,	1,036,821,23	3.47
Transportation expenses,	14,698,094.38	48.81
General Expenses,	1,223,348.06	4.06
		95.26
Total operating exp.-	$ 28,676,842.19	
Taxes-	1,458,185.96	4.74
GRAND TOTAL-	$ 30,135,028.15	100.00

The total train mileage for 1910 was as follows, figures being taken from the Auditor's 503 report:-

Revenue Service:

Freight train miles-	12,212,090
Passenger train miles-	10,119,331
Mixed train miles-	481,448
Special train miles-	23,747
	22,836,616

Non-revenue Service:

Non-revenue train miles-	606,438
TOTAL TRAIN MILEAGE-	23,443,054

In addition to the above, the light engine mileage amounted to 4,641,221 locomotive miles, sothat the total locomotive mileage was 28,084,275 miles.

The average cost per train mile as derived from the above figures was $1.29.

As a comparison with previous years, there is given below a statement showing the total train mileage and average cost per train mile for each year from 1904 to the present time.

Year.	Train Mileage.	Average Cost Per Train Mile.
1910	23,443,054	$ 1.29
1909	21,448,711	1.24
1908	21,176,790	1.22
1907	21,750,614	1.19
1906	18,743,250	1.14
1905	17,647,909	1.14
1904	16,259,861	1.14

Complete figures for the year 1911 are not available, but indications are that the average cost per train mile for the year ending June 30,1911, will be $1.33 per train mile.

It is interesting to note in the above statement, that while the train mileage increased about ten per cent from 1904 to 1906, the average cost per train mile remained the same. It is also noted that between 1906 and the present time the cost per train mile increased in almost the same ratio as the train mileage. If this increase should continue it is to be expected that eventually the cost per train mile for operating expenses,will equal or exceed the revenue per train mile, in which case the road will be in shape for receivership. In anticipation of such increased cost some plan should be worked out to decrease the cost ratio and thus keep the road a paying proposition. It is not to be assumed however, that the cost per train mile is entirely indicative of the cost of operation as compared to the gross revenue, as there may have been sufficient changes in the tonnage, ~~ratings~~ on account of heavier motive power, to increase the gross ton mileage, without increasing the gross train mileage, in which case there would be expected some increase in the cost per train mile.

To show that the general tendency for the past two decades has been an in-creased cost per train mile, there is given a table compiled by Prof. Webb, showing the average cost per train mile for the whole United States from 1890 to 1904.

Year.	Average Cost Per Train Mile.
1890	$ .96
1891	.96
1892	.97
1893	.97
1894	.93
1895	.92
1896	.94
1897	.93
1898	.96
1899	.98
1900	1.07
1901	1.12
1902	1.18
1903	1.27
1904	1.31
1910	149

The low point reached in 1895 is ascribed to the panic of 1893, but from that year until the present time the cost has steadily increased.

The cost per train mile of ten large systems in the United States, for the year 1904 was also compiled by Prof. Webb, and is reproduced below in order to show the variation in the cost per train mile on different lines even during the same period. It will be noted that for that particular year the Frisco operated $0.09 per traim mile cheaper than the average of the ten roads given. The table follows:

Name of Road.	Mileage Operated.	Cost Per Train Mile.
Canadian Pacific,	8,382	$ 1.32
C. B. & Q.	8,326	1.31
C. & N. W.	7,412	1.14
Southern Ry.,	7,197	1.05
C. RM I. & P.,	6,761	1.20
Northern Pacific,	5,619	1.39
A. T. & S. F.,	5,031	1.31
Great Northern,	4,489	1.46
Illinois Central,	4,374	1.11
Atlantic Coast Lines,	4,229	.98

Average of ten------------------$ 1.23

A study of the increase in the cost of operation from 1890 to the present time shows that the increase was not at all unwarranted, and the causes of the increase can nearly all be traced.

There are also good reasons to believe that the increased cost is actually not as great as the figures indicate. Previous to 1907 each railroad kept its accounts according to its own methods, and many items whcih are now charged to maintenance accounts were then charged to additions and betterment account, with the result that the operating expenses appeared low. After the "Interstate Commerce Act" a uniform sydtem of accounting was prescribed by the Interstate Commerce Commission and since July 1907 the accounts of all roads have been kept in accordance with this ruling.

The greater portion of the increase in cost per train mile was chargeable to maintenance of way and maintenance of equipment. The increased cost of maintenance of way was largely caused by a rapid increase in the price of labor, and by increased standards of maintenance, which in turn were caused by the demands of the public and by heavier equipment. The increased cost of maintenance of equipment was largely caused by its more costly construction, and by the demands of labor unions for higher wages. The cost of repairs for freight cars rose from 5.94 cents per train mile in 1897 tp 13.39 cents in 1907. Repairs to locomotives followed about the same advance. Repairs to passenger equipment showed less advance, being 2.11 in 1897 and 2.93 cents per train mile in 1907.

Along with these increases there has been a gradual advance in transportation expenses, caused by the increased cost of fuel, and large increases in pay of trainmen, enginemen, and other transportation expenses. Quite an appreciable increase in this item has been caused by the increased cost of accounting made necessary by the orders of the Interstate Commerce Commission.

The last two or three years have seen a demand from all over the country for reduction in the cost of living, and it is quite likely that the railroads will retrench as far as possible, and that the next few years will see a less rapid increased cost in train mileage figures.

Reports published by the Interstate Commerce Commission since 1907 show that the Frisco is operating about 15 cents per train mile below the average for the whole United States. The question is naturally raised as the the reason for this low cost of operation. At first glance it might appear very favorable, but there are several conditions of operation to be considered before we could justly arrive at such a conclusion. The cost per train mile cannot always be taken as a measure of the economy in operation. That this is true may be easily proven when it is evident that an additional train may be put in service to handle a given traffic, without affecting all of the items of operating expense. For example, one railroad may handle a given tonnage with one train, thereby indicating a high cost per train mile, while another road may handle the same tonnage in two or more trains, indicating a low cost per train mile. Yet the first road would undoubtedly show a greater net revenue because the operating revenue will be applied to one train mile and not to two or more train miles.

The above ststement shows that it is not altogether logical to compare the cost of operation on the Frisco and the cost of operation in the United States on the train mileage figures. The Frisco hauls above the average of high class commodities, which has a tendency to bring its train mileage figures above the average. However, an analysis of the cost of operation for all the accounts, shows the Frisco to be considerably below the average in certain cases, some of which present a very favorable showing and some otherwise. A comparison with the averages for the United States for several years, shows that Frisco maintenance of way expenses were two per cent below the average, tie renewals were 80% above the average, while rail renewals were only one-third of the average. While this indicates that the road is not keeping up on its rail renewals, this condition will probably not exist after a few years when the cost of tie renewals will be so decreased that the rail can be brought up to standard with no increase in operating expenses. Maintenance of equipment was six percent below the average for 1910. The reason for this is apparent after noting the additions and betterment account to equipment during 1910, the new equipment purchased costing over $5,000,000. A large portion of this equpiment was put in service during the fiscal year, reducing the cost of operation for that year very materially on account of the reduction in cost of maintenance of equipment. Expense of conducting transportation was 12% below the average, and is distributed very evenly among the different items.

The number of train miles depends in quite a measure on the class of commodity handled. Perishable freight must be moved rapidly, and the Frisco handles a great deal of perishable freight. Comparison with the average of the country shows that the Frisco handles 100% above the average on products of agriculture and forest, 25% above the average of animals and animal products, 25% above the average on merchandise and 20% below the average on mine products.

Below is a statement showing the classification of revenue freight by commodities for years ending June 30, 1909 and June 30,1910, compared with the Interstate Commerce Commission report showing total commodities handled in the United States.

	% of whole. Frisco 1909.	1910.	% of whole. Average for U.S.
Products of agriculture-------	15.96	14.80	8.62
Products of animals----------	3.83	3.47	2.29
Products of mines--	40.21	40.41	53.39
Prod. of forests---	21.51	20.72	11.38
Manufactures-------	13.35	15.44	15.41
Merchandise--------	4.86	4.94	3.89
Miscellaneous------	.28	.22	5.02
Totals----	100.00	100.00	100.00

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Discussion of Increase in Cost of Operation by Additional Train to Handle A Given Traffic.

As the number of passenger trains on a railroad is practically independent of the physical characteristics of the railroad, it is obvious that no saving in the number of passenger trains will ordinarily be effected by grade reduction. There may be isolated cases on transcontinental service where this would not be strictly true. But the value of reducing the NUMBER of passenger trains by means of grade reduction has no plausible entry in this discussion as it not be conceivable that such a thing could be done.

The greatest saving in grade reduction will, then, be in the cost of operation of freight traffic. Incidental to the saving in cost of operation of freight trains will be a saving in the cost of operating passenger trains, without changing the number of trains. This saving will be represented in a greater or less degree in all the large items of operating expense.

Before it can be determined what saving can be made in the operation of freight trains by any grade reduction, it will be necessary to determine the present cost of operation per freight train mile in all its details. After arriving at the cost per mile, we can proceed to determine what items of operating expense will be affected and in what proportion by the addition of one train to handle the same traffic. We will then have a basis for figuring the saving in operation to be made by reducing the number of trains to handle the same traffic.

There has been previously given a copy of that portion of the Annual Report for 1910 showing the cost for each item of operating expenses and its proportion to the total cost. However, this report does not separate the items into freight and passenger statistics, and as we know the freight train mile costs more than the passenger train mile, we will be obliged to determine as accurately as possible the cost for each class of mileage from the figures available. Fortunately, in addition to the annual report we have three other reports as follows:-

Form 501--Classification of Maintenance of Way and Structures, and Transportation Expense for each month of the fiscal year.

Form 503--This form shows in detail each item of operating expense for each month of the fiscal year, also the train mileage, etc.

Form 504--A statement of divisional freight statistics for each month of the fiscal year.

With the help of these statistics we will be able to determine with a considerable degree of accuracy the percent of each item which should be charged to freight and the per cent which should be charged to passenger mileage. And we can also determine the per cent of each item which will be affected by an additional train.

Following is a table showing each item of operating expense for the year 1910, the per cent each item bears to the total operating expenses, and the per cent of each item which should be charged to freight and passenger train mileage. Each class of mileage is further subdivided to show the per cent each class of mileage will be affected by - additional train. From this table and with the total train mileage ~~xtmxt~~ statistics, we will derive the cost per freight train mile for the fiscal year 1910, the cost per passenger train mile for same year, and the cost per train mile of an additional train to handle each class of mileage.

Following the table is a statement showing the basis of deriving the various conclusions. As already stated it is not expected that the figures for passenger train mileage will be of much benefit in consideration of this feature of grade reduction, but in further calculations in reference to distance, curvature and gradients the figures will be of value, hence will be determined at this time, which will simplify the calculations. In deriving the figures in this table, departure is made from the methods ordinarily employed. It is noted that in grade reduction on the Union Pacific, no attempt was made to determine the cost of freight train mileage as separated from passenger train mileage, and the entire calculations were based on the assumption that cost of operation was the average cost of $1.17 per train mile, such figure being an average of four years previous. The additional train on this assumption was estimated to cost 43.29% of $1.17 or $0.50, to which was added $.01 for interest on additional locomotove and caboose per train mile.

Items such as superintendence, etc., the per cent of which cannot be otherwise divided between passenger and freight mileage, will be proportioned according to the total train mileage. Mixed train mileage is arbitrarily separated 75% tp freight and 25% to passenger mileage. Non-revenue service mileage is arbitrarily separated 90% to freight and 10% to passenger mileage. The total mileage and per cent of each class to the whole as derived in this manner is as follows:-

	Freight	Passenger
Freight train miles	12,212,090	
Passenger train miles		10,119,331
Mixed train miles	361,086	120,362
Special train miles	23,747	
Non-revenue servive mi-	545,794	60,644
TOTAL----	13,142,717	10,300,337
Per cent of whole	56%	44%

MAINTENANCE OF WAY AND STRUCTURES.

		FRT. TRN. SERVICE			PASSENGER TRN SER.		
	% of Whole	Charged to Frght Service	% Aff'd by Add'l Train	% Cost per Add'l Train	Charged to Pssgr service	% Aff'd by Add'l Train	% Cost per Add'l Train
1-Superintendence,	1.22	.68	00	00	.54	00	00
2-Ballast,	.17	.10	00	00	.07	00	00
3-Ties,	4.44	3.21	12.50	.40	1.23	12.50	.12
4-Rails,	.52	.38	24.00	.09	.14	24.00	.03
5-Other track mat'l	.84	.62	24.00	.15	.22	24.00	.05
6-Roadway & Track							
a-Trk. maint'n	3.28	2.40	24.00	.58	.88	24.00	.21
b-Appl.trk,mtl	1.58	1.15	13.90	.16	.43	13.90	.06
c-Cut weeds & gen cleaning	.58	.32	00	00	.26	00	00
d-Dch & bnk wdng	.40	.22	00	00	.18	00	00
e-Chg algn & gra	.04	.04	00	00	00	00	00
f-flood damage	.17	.10	00	00	.07	00	00
g-BankProtection	.01	.01	00	00	00	00	00
h-Filling	.04	.02	00	00	.02	00	00
i-Oth care road-way & track	.31	.17	00	00	.14	00	00
7-Rem snow & ice	.05	.03	00	00	.02	00	00
8-Tunnels	00	00	00	00	00	00	00
9-Br-trest & culvts							
a-e Gen repairs	2.84	1.59	00	00	1.25	.00	00
f-Flood damage	.03	.02	00	00	.01	00	00
10-Over & undergrade crossings	.02	.01	00	00	.01	00	00
11-Grd Xings C. G.& signs	.42	.24	00	00	.18	00	00
12-Snow & sand fenc	00	00	00	00	00	00	00
13-Sig & interlkr	.19	.11	10.00	.01	.08	10.00	.01
14-Tel & TElph line	.38	.21	00	00	.17	00	00
15-Elec power trans	00	00	00	00	00	00	00
16-Bldgs fxtr &grnd							
a-Trans Building	.62	.43	00	00	.19	00	00
b-Fuel & wtr sta	.36	.22	10.00	.02	.14	10.00	.01
c-Shop eng & TT	.31	.17	00	00	.14	00	00
d-Other building	.09	.05	00	00	.04	00	00
17-Docks & wharves	00	00	00	00	00	00	00
18-Road'y tools Sup	.33	.23	16.00	.04	.10	16.00	.02
19-Injuries persons	.09	.05	00	00	.04	00	00
20-Stat & printing	.06	.04	00	00	.02	00	00
21-Other expenses	.01	.01	00	00	00	00	00
22-Maint.jt tr-Dr.	.30	.17	00	00	.13	00	00
23-Maint.jt tr-Cr.	.49	.27	00	00	.22	00	00
Total M. of W. Strs	19.21	12.73		1.45	6.48		.54

MAINTENANCE OF EQUIPMENT.

	% of Whole	FRT. TRN. SERVICE: Charged to Frght Service	FRT. TRN. SERVICE: % Aff'd by Add'l Train	FRT. TRN. SERVICE: % Cost per Add'l Train	PASSENGER TRN SER: Charged to Pssgr Service	PASSENGER TRN SER: % Aff'd by Add'l Train	PASSENGER TRN SER: % Cost per Add'l Train
24-Superintendence	.52	.39	00	00	.15	00	00
25-Rep St. Locomo.	9.95	6.47	85.60	5.54	3.48	85.60	2.98
26-Renewals Loco.	.02	.01	85.60	.01	.01	85.60	.01
27-Depreciation Steam Locomo-	.08	.05	85.60	.04	.03	85.60	.02
28-Electric loco-tives-repairs	00	00	00	00	00	00	00
29-Electric loco-motive renewal	00	00	00	00	00	00	00
30-Elec. locomoti-ves-depreciatn	00	00	00	00	00	00	00
31-Passenger train cars-repairs,	1.50	00	00	00	1.50	00	00
32-Passenger train cars-renewals	.01	00	00	00	.01	00	00
33-Passenger train cars-depreciation	.03	00	00	00	.03	00	00
34-Freigt car repr	6.30	6.30	00	00	00	00	00
35-Freigt car renw	.21	.21	00	00	00	00	00
36-Freight cras-depreciation	.19	.19	00	00	00	00	00
37-Elec. Equipt of cars-repairs	00	00	00	00	00	00	00
38-Elec. Equipt of cars-renewals	00	00	00	00	00	00	00
39-Elec. 3quipt of cars-deprectn	00	00	00	00	00	00	00
40-Floating equip-ment-repairs	00	00	00	00	00	00	00
41-Floating equip-ment-renewals	00	00	00	00	00	00	00
42-Floating equip ment-deprecetn	00	00	00	00	00	00	00
43-Work equip-repr	.22	.14	10.00	.01	.08	10.00	.01
44-Work equip-renw	.01	.01	10.00	00	00	00	00
45-Work equip-depn	.01	.01	10.00	00	00	00	00
46-Shop mach&tools	.53	.38	42.00	.16	.15	42.00	.06
47-Power plt equip	00	00	00	00	00	00	00
48-Injuries to per	.12	.09	42:00	.04	.03	42.00	.01
49-Stat & Printing	.04	.03	42:00	.01	.01	42:00	00
50-Other expenses	00	00	00	00	00	00	00
51-Maint.Jt. Equip at Terminls-Dr	.01	.01	00	00	00	00	00
52-Maint.Jt. Equip at Terminls-Cr	.04	.03	00	00	.01	00	00
TOTAL MAINT. EQUIP	19.71	14.24		5.81	5.47		3.09

TRAFFIC EXPENSES.

	% of Whole	FRT. TRN.SERVICE: Charged to Frght Service	% Aff'd By Add'l Train	% Cost per Add'l Train	PASSENGER TRN SER: Charged to Pssgr Service	% Aff'd by Add'l Train	% Cost per Add'l Train
PASSENGER							
53-a-Superintendce	.28	00	00	00	.28	00	00
54-a-Outside Agencies-	.53	00	00	00	.53	00	00
55-Advertising	.55	00	00	00	.55	00	00
56-a-Traffic Assns	.02	00	00	00	.02	00	00
57-a- ------------							
58-a-Indust & Immigration bureu	.03	00	00	00	.03	00	00
59-a-Staty & Prntg	.18	00	00	00	.18	00	00
60-a-Other expens	00	00	00	00	00	00	00
FREIGHT							
53-b-Superintendce	.54	.54	00	000	00	00	00
54-b-Outside Agencies-	.78	.78	00	00	00	00	00
55-b-Advertising	.01	.01	00	00	00	00	00
56-b-Traffic Assns	.05	.05	00	00	00	00	00
57-b-Fast frt lins	00	00	00	00	00	00	00
58-b-Industrial & Immig bureaus	.08	.08	00	00	00	00	00
59-b-Staty & Prntg	.41	.41	00	00	00	00	00
60-b-Other Expense	.01	.01	00	00	00	00	00
TOTAL TRAFFIC EXP.	3.47	1.88			1.59		

TRANSPORTATION EXPENSES.

Supervising Transportation.							
61-Superintendence	1.32	.74	00	00	.58	00	00
62-Dispatching Trs	.64	.41	00	00	.23	00	00
SUB-TOTAL----	1.96	1.15	00	00	.81	00	00
Station Service.							
63-Station Employs							
(a) Passenger	.80	00	00	00	.80	.15	.12
(b) Freight	4.25	4.25	15.00	.64	00	00	00
(c) Telg. & tel Operators	1.05	.79	15.00	.12	.26	15.00	.04
64-Weighing and car Service Assocns	.18	.18	00	00	00	00	00
66-Station supplies and Expenses	.44	.33	00	00	.11	00	00
SUB-TOTAL----	6.72	5.55		.76	1.17		.16

TRANSPORTATION EXPENSES-Continued.

Yard Service	% of Whole	FRT. TRN. SERVICE: Charged to Frght Service	% Aff'd By Add'l Train	% Cost Add'l Train	PASSENGER TRN SER: Charged to Pssgr Service	% Aff'd By Add'l Train	% Cost Add'l Train
67-Yard masters & Their clerks,	.73	.61	See	Total	.12	See	total
68-Yard conductors and brakemen,	2.17	1.82	"	"	.35	"	"
69-Yard switch and signal Tenders	.07	.06	"	"	.01	"	"
70-Yard supplies and expenses	.03	.02	"	"	.01	"	"
71-Yard enginemen	1.23	1.03	"	"	.20	"	"
72-Enginehouse expenses-yard,	.39	.33	"	"	.06	"	"
73-Fuel for yard locomotives;							
(a)-Fuel--	1.09	.92	"	"	.17	"	"
(b)-Oper. fuel Sta's-yard	.03	.02	"	"	.01	"	"
74-Water-Yd.Locomo	.07	.06	"	"	.01	"	"
75-Lubri-Yd.Locomo	.04	.03	"	"	.01	"	"
76-Other Supplies for yard locomo	.04	.03	"	"	.01	"	"
77-Operation Jt.Yds and terminls-Dr	.76	.64			.12		
78-Operation Jt.Yds and terminls-Cr	.62	.52			.10		
Totals-------	6.03	5.05	20.00	1.01	.98	20.00	.20
Road Eng. Service							
80-Road Enginemen							
(a)-Passenger	2.36	00	00	00	2.36	100.00	2.36
(b)-Freight	4.48	4.48	100.00	4.48	00	00	00
81-Enginehouse exp Road engines	1.40	.85	100.00	.85	.55	100.00	.55
82-Fuel-road lpco-							
(a)-Passenger	2.85	00	00	00	2.85	100.00	2.85
(b)-Freight	6.64	6.64	75.00	4.98	00	00	00
(c)-Oper.of fuel Sta.road loc	.31	.19	75.00	.14	.12	100.00	.12
83-Water-road loco	.70	.49	75.00	.37	.21	100.00	.21
84-Lubricants for road locomotiv	.24	.15	100.00	.15	.09	100.00	.09
85-Other supplies road locomotiv	.21	.11	100.00	.11	.10	100.00	.10
Totals------	19.19	12.91		11.08	6.28		6.28

TRANSPORTATION EXPENSES-Continued.

Train Service	% of Whole	Frt. Trn.Servive: Char-gedto Frght Ser-vice	% Aff'd By Add'l Train	% Cost per Add'l Train	Passenger Trn Ser: Char-gedto Pssgr Ser-vice	% Aff'd By Add'l Train	% Cost per Add'l Train
88-Road trainmen-							
(a)-Passenger	1.91	00	00	00	1.91	100.00	1.91
(b)-Freight	5.43	5.43	100.00	5.43	0000	00	00
89-Train supplies and expenses							
(a)-Care of passenger cars	.86	00	00	00	.86	00	00
(b)-Pass Tr Sup and expenses	.39	00	00	00	.39	100.00	.39
(c)-Care frt crs	.18	.18	00	00	00	00	00
(d)-Frt train Supp & Exps	.42	.42	100.00	.42	00	00	00
TOTAL--------	9.19	6.03		5.85	3.16		2.30
Casualties.							
93-Clearing wrecks	.40	See	Total		See	Total	
99-Loss-damage-frt	1.83	"	"		"	"	
100-Loss-damag-bagg	.09	"	"		"	"	
101-Damage-property	.60	"	"		"	"	
102_Damage to stock on R/W	.54	"	"		"	"	
103-Injury-persons	1.23	"	"		"	"	
Sub-Total------	4.69	2.63	50.00	1.32	2.06	50.00	1.03
Miscellaneous.							
90-Interlocking & Blk.Sig. Opertn							
(a)-Signalmen	.13	.07	00	00	.06	00	00
(b)-Sig. Supplies	.03	.02	00	00	.01	00	00
91-Crossing flag-men & gatemn							
(a)-Xing Wtchmn	.15	.08	00	00	.07	00	00
(b)-Xing Suplis	.03	.02	00	00	.01	00	00
92-Drawbrdg Opertn	.01	.01	00	00	00	00	00
94-Telegraph and tel. operation	.27	.20	15.00	.03	.07	15.00	.01
95-Oper. flot.equip	00	00	00	00	00	00	00
96-Express service							
97-Stat & Printing	.41	.31	50.00	.15	.10	50.00	.05
98-Other expenses	.06	.04	00	00	.02	00	00
104-Oper. Joint Tr &facilities-Dr	.24	.13	00	00	.11	00	00
-Oper. Joint tr &facilities-Cr	.30	.17	00	00	.13	00	00
Sub-Total------	1.03	.71		.18	.32		.06
Grand Total-Transportation Expenses----------	48.81	34.03		20.20	14.78		10.03

GENERAL EXPENSES.

	% of Whole	Frt. Trn. Service: Charged to Frght Service	% Aff'd By Add'l Train	% Cost per Add'l Train	Passenger Trn Ser: Charged to Pssgr Service	% Aff'd By Add'l Train	% Cost per Add'l Train
106-Sal. & Expens- Gen. Officers	.70	See	Total		See	Total	
107-Sal. Exp. Clerks and attendnts	1.37	"	"		"	"	
108-General office Sup. and Exp.	.23	"	"		"	"	
109-Law Expenses	.74	"	"		"	"	
110-Insurance,	.57	"	"		"	"	
113-Stat & Printng	.24	"	"		"	"	
114-Other expenses	.23	"	"		"	"	
115-Gen. Administr tion Joint Fa- cilities-Dr.-	.02	"	"		"	"	
-Gen. Administr tion Joint Fa- ccilities-Cr.-	.04	"	"		"	"	
Total Gen. Expenses	4.06	3.04	00	00	1.02	00	00

TAXES

Total Taxes	4.74	3.31	00	00	1.43	00	00

S-U-M-M-A-R-Y

M of W & Structures	19.21	12.73		1.45	6.48		.54
Maint of Equip't	19.71	14.24		5.81	5.47		3.09
Traffic Expenses,	3.47	1.88		~~20.20~~	~~14.78~~	1.57	~~10.35~~
Transportation Exp	48.81	34.03		20.20	14.78		10.35
General Expenses,	4.06	3004			1.02		
Taxes,	4.74	3.31			1.43		
Grand Total-------	100.00	69.23		27.46	30.77		13.66

MAINTENANCE OF WAY AND STRUCTURES.

1.-Superintendence.

This item will not be appreciably affected by additional train. Maintenance is divided according to mileage statement.

2.-Ballast.

This account includes the cost of ballast, but not the labor of applying. While it may be reasonably argued that the number of trains passing over a track will in some degree affect the maintenance of ballast, the per cent would undoubtedly be so small as to be negligible, hence this item is not considered as affected by additional train. Railroad men speak of ballast "wearing out" which in fact is natural deterioration, the driving of the ballast down into the roadbed, the grinding up of the particles or pieces of the ballast by trains passing over it, blowing away by winds and washing away by rains, all combined. Division of cost is made according to mileage statement.

3.-Ties.

It has been previously stated that tie maintenance for 1910 was considerably above the average, and that the rail maintenance was below the average. These facts will probably introduce slight errors in the calculations, which however, it is believed will practically balance each other.

Is was assumed at the start, it will be remembered, that the tonnage remained constant, and that the train and locomotive mileage would be increased. As affects the cost of ties the question to be considered, then, is the increased cost due to the additional locomotive and the running of two trains instead of one. It must also be determined what items make up the maintenance expense, and their relation to each other.

Ties fail by two processes; by mechanical wear and by decay. The original conception of mechanical wear is probably an erroneous one. Our timber experts now tell us that mechanical wear is in reality a combination of the original conception of mechanical wear as simple abrasion, and of decay. Sound timber of the class used for tie material does not yield appreciably to mechanical action of the rails, except in case of very soft woods and creosoted soft woods. This is evidenced by the fact that creosoted hard wood ties placed on tangent track show practically no wear after eight or nine years service, or about the natural life of untreated oak ties. The destruction of the untreated timber by the so-called mechanical wear, is principally caused by the displacement of the surface decay on the timber by the action of the rail, or ballast, thus exposing new surfaces to the action of the agencies causing decay.

Redriving of spikes also aggravates the decaying process, and in consequence the mechanical wear. The first loosening of the spike is caused by the undulations of the rail and by lateral pressure while trains are passing over the track. This loosening allows water to find its way into the spike hole, causing decay and eventually the spike becomes so loose that it must be redriven. This process continues until the tie is weakened to such an extent that it either breaks off or is taken out as unfit to longer perform its function with safety.

It is generally accepted, and fairly well proven, that the best known protection to a tie against mechanical wear, which as above stated means principally the displacement of surface decay, will lengthen the life of the tie almost 100%. By treating processes, such as zinc chloride and creosoting, the life of soft wood ties protected with metal tie plates and fastened with screw spikes, is commonly estimated to be increased as much as 150 per cent or more. The railways of Europe, who have been the pioneers in the treating of ties to prolong their life, have attained such perfection in their treating processes, and in their methods of protecting their ties against the displacement of surface decay and against decay in general, that as high as 400 per cent has been added to the life of certain woods.

As affecting the problem in hand, it is to be determined as accurately as possible, how much sooner a tie is destroyed by reason of its being in a railroad track under traffic than it would if it were simply in the track with no trains passing over it. White oak piling, if it did not have to be renewed on account of rotting at the base, would last for fourteen to sixteen years. The writer has seen white oak ties in an abandoned piece of railroad track which had been in the track for twelve years since its use was discontinued and these ties were still fit for three or more years service under ordinary operating conditions. These facts lead to the conclusion that the effect of the passage of trains is to decrease the life of the tie at least one half, or in other words, we will be reasonably safe in assuming that our ties fail 50% by mechanical wear, whatever its cause, and 50% by decay. This statement is further strengthened by the experience of the railroads who are using tie plates and screw spikes, the best known protection against mechanical wear. On our own road we are xxxx led to believe by the number of tie renewals since starting the treating processes, that the treated ties will have at least 100 per cent added to their life if protected by tie plates alone.

Any increased maintenance charge to ties on account of the number of trains run over the track will then, be dependent on the increased mechanical wear, and not on the natural deterioration of the tie. That the life of ties is less under heavy traffic is well recognized, but it is by no means certain that running two trains instead of one to carry a given traffic will decrease the life of the ties, or that portion which fails by mechanical wear, in direct ratio to the number of trains. In general it may be said that white oak ties are renewed in main lines about two years sooner than in branch lines with not over half the traffic, so that an increased cost of about 25 per cent may be reasonably ascribed to doubling the car and engine mileage.

It is believed further, that the locomotive is responsible for fully 50 per cent of the so-called mechanical wear of the ties by reason of its greater weight, the inaccuracy of the counterbalancing and initial impact, while the remaining 50 per cent is caused by the passage of the cars and is to a large extent independent of the number of cars. With these assumptions we may conclude that doubling the train mileage without increasing the car mileage will not increase the expense chargeable to maintenance of ties over 12-1/2 per cent.

Exceptions will probably be taken to some of the above statements by tie experts, on the basis that white oak ties do not fail by mechanical wear to any appreciable. extent. It may be stated, however, that the maintenance of main line track depends in a large degree on the number of trains, and it is a fact not to be disputed that ties on main line track do not give the number of years of service as in branch lines, which in turn is partly caused due to a better standard of maintenance on the main lines, as well as a more rapid deterioration of the tie.

The question of the whys and wherefores of the failure of timber is a great question in itself, and open to very much discussion and disagreement. Actual tie renewals on Frisco Lines for the past ten years show that 30 per cent more ties per mile have been renewed on main lines than on branch lines, hence the above estimate of the increased cost due to the additional traim mileage and additional engine mileage is backed by the practical experience of our railroad to a large extent.

It is noted that Mr. Berry in his statement concerning grade reduction on the Union Pacific Railroad assumed a 50 per cent increase to the maintenance by doubling the train mileage. Prof. Webb was even more radical, as seen from the writer's viewpoint, stating a 50 per cent increase by reason of operating a given tonnage with four light engines instead of three heavy ones. While it is true to a certain extent as stated by Prof. Webb, that "experience shows that the expense of repairs of roadway have a singular uniformity per train mile, regardless of whether the traffic is light or heavy" this fact is dependent principally on the standard of maintenance adopted, and the statement would seem to be further evidence against Prof. Webb's own assertion that an increase of 50 per cent would be incurred in the cost of maintenance of ties by simply increasing the number of trains from three to four.

In dividing the total cost of maintenance of ties between freight and passenger mileage, 50 per cent will be divided according to the car mileage, for reasons given above.

A statement of the total locomotive mileage for fiscal year 1910 divided in the same manner as the total train mileage statement previously given, follows on the next page:-

	Freight.	Passenger.
Freight locomotive mileage	12,570,756	----------
Passenger " "	--------	10,306,712
Mixed " "	361,663	120,554
Special " "	23,998	--------
Switching " "	3,555,413	395,045
Non-revenue " "	675,121	75,013
Total Locomotive Mileage	17,186,951	10,897,324
Per cent of total	61 %	39 %

The total freight car mileage, loaded and empty, and including caboose mileage, was 245,904,276, and the total passenger car mileage was 48,052,091. Freight car mileage thus represented 84 per cent of the total car mileage, and passenger car mileage 16 per cent of the total car mileage.

4.-Rails.

Rail deterioration as affecting ordinary maintenance or renewal is due almost entirely to mechanical wear. Some loss will result from oxidation due to exposure, and there will be further oxidation caused by the catalytic action of the salt brine from refrigerator cars. These losses are very small however, compared with abrasion by flanges and treads. Abrasion is increased by deformation of ball of the rail by impact, causing running of the rail head, thus exposing angular portions to abrasions by flanges. That the weight of locomotives of the present day is principally responsible for this deformation is shown by the fact that light rail in branch lines has withstood the service of from twenty to twenty five years without noticeable deformation, where the weight on the driving wheels of the locomotives used did not exceed greatly the wheel loads of our heaviest equipment. It is also noticeable that many small lines have been built in the past ten years, where the engines and equipment used were light as well as the rail, and that this rail is giving just as good service as the much older rail on many of the larger roads. On the other hand the weight on the driving wheels of our heaviest locomotives in some cases approaches the crushing strength of the rail, so that we are not surprised that with the increased strains due to impact at high speeds, we find the heaviest rail is soon deformed if the track is not in perfect line and surface.

It is safe to say that on straight track there would be no appreciable difference in the mechanical wear on the rails by running a given tonnage over them in two sections instead of one, exclusive of the wear caused by the locomotive. On curves and uneven grades this will probably not be strictly true as many different forces are set up in a long train than are found in a short one. We would expect the net results to be so nearly the same, however, that the difference is negligible.

As the mechanical wear depends on abrasion, which in turn is in direct ratio to the weight, it would seem reasonable to say the destructive effect isin proportion to the weight, as long as it is below the elastic limit of the material. To this should be added the effects of impact which may be assumed as about equal to the weight at average speeds.

On curvedtrack the outer rail nearly always wears out much faster than on straight track. This is caused by it being impossible to elevate the outer rail properly for all speeds, or perhaps it would be better to say that it is because all trains do not run or cannot run over the curved track at the speed for which it is elevated. If the curve is on a grade the train running slowly up the grade will probably determine the elevation possible. To prevent the high speeds trains coming down the grade in the opposite direction from being derailed on account of insufficient elevation the rail is given such elevation that it is probably too much for the slow speed trains and not sufficient for the high speed trains. Thus the rail is subjected to improper wear in both directions. The increased wear on the the outer rail will of course be due to increased weight or thrust against it caused by the greater centrifugal force of the fastertrain, and to the increased abrasive action of the slower train due to the too great elevation throwing the weight toward and against the side of the rail head. For example, consider an engine with total weight of 100 tons on a four degree curve with no elevation and running thirty miles per hour. The total increased pressure on outer rail due to centrifugal force would be expressed by the formula:-

$$f = \frac{Wv^2}{Rg}$$

or f = four tons.

Consider on the other hand a box car of 20 tons weight on the same curve at the same speed. The total increased pressure would be only .8 ton or one-fifth that of the engine.

On such a basis of figuring, but without going into the details, it can be shown that on the Frisco System, taking into account the per cent of straight and curved track, the wear of the rails due to curvature will amount to six times as much per locomotive mile as it does per car mile.

The average total weight of locomotives for the system is 1.8 times the average weight of cars plus estimated average load.

In the shape of an equality the total mechanical wear per locomotive mile as compared to car mile would be as follows:-

$$2 \times 1.8 + 6 = 9.6$$

In 1910 the total locomotive mileage was 18,084,275 miles equal on above basis to 269,609,040 car miles. The total car mileage was 293,956,367 miles. In other words ~~the~~ on the basis named the locomotives should have caused 48% of the total charge due to maintenance of rail. As rail will ordinarily have 50 per cent of its life remaining after being taken out of main line we may assume the net effect of doubling the locomotive mileage as affecting the rail account, to be 24 %. Thus as the tonnage remains constant, the increase by reason of additional locomotive would be 24 per cent of total chargeable to this account.

In dividing the total cost of maintenance between freight and passenger, 48% will be divided according to total locomotive mileage statement, and 52% according to total car mileage statement.

5.-Other track material.

This item includes track fastenings, frogs and switches, tie plates, guard rails, etc. Maintenance of spikes and tie plates will follow the same proportion as maintenance of ties, less their scrap value, which is not usually credited to these items, but which however is very small compared to the total. The remaining items will follow approximately the same proportions as rails. As the first items are only about one per cent of the total, it will be assumed the whole account follows the rail proportionment, and it is so divided in the table.

6.-Roadway and Track.

This account includes 6.41 per cent of the total operating expenses, hence the items should be given careful consideration.

(a).-Track Maintenance:-This item includes the pay of employes engaged in aligning, surfacing and gauging tracks, placing and removing track shims and tightening bolts and spikes in tracks. When a track is taken up, the labor expended therefor is chagged to this account, whether a new track is laid to take its place or not.

As this account does not include the cost of applying any new material, it is evident it is determined by the locomotive and car mileage. If the arguments advanced under discussion of rail are correct, the same figures would hold good under this account,--namely, that 48 per cent of expense of track maintenance is caused by the locomotive and the remainder by the train. Additional train would then affect 24 per cent of the whole.

There may be some error in separating the total amount between freight and passenger service on the basis of locomotive and car mileage, due to the fact that the cost of track maintenance will not actually be the same per freight car mile as per passenger car mile. As it would be manifestly impossible to make an accurate determination of the difference in cost of the two classes of mileage, we must accept the most reliable figures we can obtain in making the division. Though there will be some error in making the division on the car mileage basis, it will undoubtedly be small compared to the whole.

(b).-Applying track material:-It is estimated that 75 per cent of the total operating charge to this account will be charged to tie renewals, this being the per cent chargeable to this one item as taken from time books covering a long period. Under consideration of ties it was estimated 12 1/2 per cent of the total would be affected by additional train. The same should be true of the portion of the charge to applying track material which includes tie renewals.

The remaining 25 per cent of the item will evidently be affected in the same proportion as the accounts for rail and other track material,--namely 24 %. In distributing the total between freight and passenger service 75 % will be distributed according to the distribution of the tie account and the remainder according to the distribution of the accounts for rail and other track material.

(c).-Weeds:-This account to which is charged the cost of cutting weeds, will not be affected by additional train. Total is distributed according tototal train mileage statement.

(d)Ditching ahd Bank Widening:-Will not be affected by additional train. Total is divided according to total train mileage statement.

(e).-Changing Alignment and Grades:-About the only logical way to consider this item would be to say that provided the change in alignment and grade was an economy, the amount which this item represents would have been distributed into other operating expenses if the changes in alignment and grade had not been made. In case of a very large reduction in grade at some point, with a large charge to this account, it would not be proper to make such an assumption, and the account would more properly be left out, or some reasonable interest figured on the total and the cost per train mile of the interest charge added to the other cost finally derived. As the total of this account for 1910 is very small, it will be arbitrarily assigned to the freight column, the amount which might be assigned to the passenger column being too small to take into account. The item is of course not affected by the additional train.

(f).-Flood Damage.

(g).-Bank Protection.

(h).-Filling.

(i).-Other Care Roadway and Track.- None of these four accounts will be affected by number of trains. The sub-division of the total is made according to the total train mileage statement.

7.-Removal of Snow and Ice:-

8.-Tunnels:-

These two items will not be affected by the number of trains. Sub-division of the items is made according to the total train mileage statement.

9.-Bridges, Trestles and Culverts:-In grade reduction on the Union Pacific Railroad, Mr. Berry figured 5 % of this item would be affected by additional train. He made no explanation as to how he arrived at such a conclusion and it is not clear upon what basis it would be reasonably argued that any appreciable portion would be affected.

Our truss bridges are so designed that they are not affected by the number of trains as long as the load is less than the elastic limit of the material, and they rust out or are taken out on account of the increase in size of motive power and equipment long before their usefulness has been affected by the number of trains passing over them. We consider our steel bridges as permanent structures, and so far as experience has shown they are permanent structures in so far as the number of trains run over them affects their life. On the old pin connected light spans which are being overstrained by too heavy power, there would possibly be an inappreciable excess of wear on the parts due to vibration and impact, but the amount would be too small to enter into these calculations.

In the case of culverts the same arguments hold, and no appreciable portion of the maintenance of culverts could be charged to an additional train.

There are some reasons for believing that the maintenance on pile and frame bridges may be increased slightly by running an additional train, on account of the additional locomotive. This would be principally on bridges on curved track, making more frequent alignment necessary. As there are very few bridges, and as most of our bridges remain as originally built until ready for renewal, it may be said that the increased cost due to additional train is too small for calculation.

The items of this account are divided according to the train mileage statement.

10.-Over and Undergrade Crossings:-Not affected by the number of trains. Divided according to the total train mileage statement.

11.-Grade Crossings, Cattle Guards, Fences and Signs:- Of these items, maintenance of cattle guards is the only item which could be affected. Same arguments would hold as in pile and timber bridges, however, and no account will be taken of any increased operating charges because of additional train. Total is divided according to the total train mileage statement.

12.-No charge.

13.-Signals and Interlocking Plants:-This item will undoubtedly be increased by additional train, though to just what extent it is difficult to say, as it is a more or less arbitrary item. If the account were sub-divided to show the maintenance charge to the automatic signals and to the mechanical signals, it would be possible to make a fairly accurate estimate as to the per cent affectes by additional train. As these figures are not available, estimate is made by comparing the present total for the account, together with the mileage, to the total for this account together with the mileage, before any electric block signals were used. In this manner it is estimated that 10 per cent is affected by the train mileage, this proportion about representing the increased cost indicated if the train mileage was doubled. The total is divided according to the total train mileage statement.

14.-Telegraph and Telephone Lines:-Maintenance accounts chargeable to this item will not be appreciably affected by the number of trains run. Total is divided according to the total train mileage statement.

15.-Electric Power Transmission:No Charges.

16:-Buildings, Fixtures and Grounds:-

(a),-Transportation Buildings:-It is believed that the maintenance expenses chargeable to this account should be divided in the same ratio as each class of revenue bears to the total operating revenue. The reason for this is that the value of transportation buildings follows this division more closely than it does a division on the train mileage basis.

(b).-Fuel and Water Stations:-A portion of these items willl be affected by the number of trains, the remainder is chargeable to maintenance necessitated by natural causes of decay and depreciation. As it will not be possible to make an accurate estimate from any figures kept, it will be arbitrarily assumed 10 per cent is affected by additional train. It can be reasonably said as much as ten per cent will be affected and a smaller figure would be inappreciable in the calculations. The total is divided according to the total train mileage statement.

(c).-Shops, Enginehouses and Turntables:-

(d).-Other Buildings:-

Item (c) may be increased to a very small extent by housing and turning additional locomotive, but the amount will be inappreciable. Both items are divided according to the total train mileage statement.

17.-Roadway Tools and Supplies:-This account will be affected in the same proportion as "roadway and track". Of that account 71% of the total was charged to freight service and 29% to passenger service. Sixteen per cent of the total charged to each class of service was found to be affected by additional train. Division of account "Roadway, ~~xxx~~ Tools" and Supplies" will be made in this manner.

19.-Injuries to Persons:-

20.-Stationery and Printing:-

21.-Other Expenses:-

22.-Maintaining Joint Tracks-Dr.-

23.-Maintaining Joint Tracks-Cr.-

None of the above five accounts will be appreciably affected by an additional train. They will be all divided according to total train mileage statement. There may be some slight error in this division, but it will be inappreciable in the whole.

Total Maintenance Of Way And Structures.

The total per cent cost for additional train as indicated by above figures is 1.45% of total operating charge per mile, for additional freight train, and .54% of total operating charge per mile for additional passenger train.

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MAINTENANCE OF EQUIPMENT.

24.-Superintendence:-This account will not be appreciably affected by additional train. Total expense of car repairs amounts to 46% of total repairs to locomotives and cars. The sub-division of total account will be divided therefore, 46% according to the car mileage statement and 54% according to the locomotive mileage statement.

25.-<u>Steam Locomotives - Repairs</u>:-This account is 9.95% of the entire operating expenses. No records are kept by the Mechanical Department showing the distribution of locomotive repairs divided as to different classes of engine mileage. By a long and tedious process the Mechanical Department's form K-860-100 could be used in making such a separation. It would, however, be necessary to know the exact condition of each engine at the beginning of the fiscal year, see that no repairs were counted made on equipment sent to shop in the previous fiscal year, and to estimate the amount of repairs necessary to all motive power at the end of the fiscal year to place it in similar condition to what it was at the beginning, allowing for depreciation. When the result was obtained it would be in error, because engines ordinarily classed as freight locomotives are often used for passenger service and vica versa.

There has already been given a statement showing total locomotive mileage, which was used in making certain estimates in maintenance of way and structures expenses. This statement includes the total mileage of all locomotives on Frisco rails for the fiscal year in question. However, these locomotives were not all Frisco locomotives or locomotives on which the Frisco makes general repairs. For this reason there should be developed a statement showing the total locomotive mileage of engines on Frisco rails on which Frisco makes general repairs. Such a statement is given below, but it will be noted in the deductions made, no separation of different classes of locomotive mileage is given in miles of engines of other companies on which the Frisco makes no general repairs, or in miles of Frisco engines leased to other companies on which the Frisco does make general repairs. This statement must first be separated to give as nearly as possible the actual engine mileage by classes on which Frisco makes repairs and which operate on Frisco Lines.

Exception is taken to the Auditor in charging repairs on engines of Frisco leased to other companies to operating expenses on the Frisco. As the mileage of these locomotives is only 3% of the total locomotive mileage, the error will be correspondingly small, and no figures are available for separating the charges.

	Mileage.
Freight locomotive miles,	12,570,756
Passenger locomotive mileage,	10,306,712
Mixed locomotive mileage,	482,217
Special locomotive miles,	23,998
Switching locomotive miles,	3,950,458
Total------------------------	27,334,141
Less----	
Miles of engines of other companies on which Frisco makes no general repairs,--------------------	2,216,336
	25,117,805
Plus----	
Miles of Frisco engines leased to other companies on which Frisco makes general repairs------------------------------	808,318
Net Revenue Miles-------------	25,926,123
Non-revenue Service-----------	750,136
Total Locomotive Mileage ----	26,676,257

In order to arrive as nearly as possible at correct mileage of locomotives on Frisco rails on which Frisco makes repairs, the 2,216,336 miles of locomotives of foreign roads will be divided according to the percentage each class of mileage bears to the total of 27,334,141 miles, and these amounts will be deducted from each class of mileage. The miles of Frisco engines leased to other companies on which Frisco makes repairs, will be divided in same manner and added to each class of mileage. Then the non-revenue mileage will be divided into different classes according to the per cent each bears to the entire mileage.

A statement of the total mileage divided on this basis follows, with a column showing the per cent each item bears to the whole.

Mileage.	Totals	Percent of whole.
Freight locomotive miles,	12,268,130	46.0
Passenger locomotive miles	10,058,689	37.7
Mixed locomotive miles	470,375	1.8
Special locomotive miles	23,340	.1
Switching locomotive miles	3,855,723	14.4
Total ------------	26,676,257	100.00

It will be seen from the above statement that only 856 per cent of the total locomotive mileage enters into the total train mileage.

If we assume that the repairs to switch engines are approximately the same as the average of repairs to freight and passenger engines, we find 85.6 per cent of 9.95% or 8.52 per cent of total operating expenses will be chargeable to repairs of road locomotives.

As an additional train means an additional engine, 85.6 per cent of the total repairs to road engines, or 100 per cent of that portion chargeable to road engines, will be affected by additional train. There may be exception taken to this statement on the basis that the cost of repairs depends on the tonnage handled or on the ton mile basis instead of on the train mile basis. Prof. Webb took the ton mile view in his writings and stated there would be no additional repair expense in handling a given tonnage with four light engines instead of three heavy ones. His view is undoubtedly wrong from a practical standpoint, though there are some arguments in its favor from a theoretical standpoint. As a matter of fact, when additional engines are placed in service, they are practically always engines of the same class or a heavier class than those already in operation, and it is quite reasonable to assume that the additional engine hauling a portion of the given tonnage at a higher speed will require the same repairs. There is also another important point in engine maintenance, not mentioned by Prof. WebbM-Engines must be shopped frequently for cleaning and tightening flues and staybolts, both of which are entirely independent of the tonnage, but quite evidently about in proportion to the number of miles they have been run, or in other words to the time in service, which is practically the same thing, under ordinary operating conditions.

In dividing the total charge between freightand passenger service, it must be remembered that passenger engines require about twenty per cent less repairs per engine mile than do freight engines. If we should divide the expense of repairs on the basis of the total mileage statement, we would then be in error. By making the mileage statement correspond to the relative cost of repairs, we can do this, however. The last table given shows the total freight mileage was 12,268,130 miles. If the passenger engine repairs cost twenty per cent less per locomotive mile, this same freight mileage on a comparative basis with the passenger mileage would have been 15,335,162 miles. In other words, if the repairs to the freight engines cost the same as the repairs to passenger engines, the freight engines could have run 15,335,162 miles for the same total cost of repairs as were actually represented in running 12,268,130 miles. The mixed train mileage will be separated as formerly, 75% to freight and 25% to passenger, the division being 352,781 miles to freight and 117,594 miles to passenger. On the above basis of cost of repairs, the 352,781 freight miles would represent 440,976 passenger miles. Assigning the 23,340 miles of special locomotive mileage arbitrarily to freight- we would then have on a comparative basis a total of 15,799-478 freight locomotive miles, and 10,176,283 passenger locomotive miles.

The repairs to freight locomotives would on this basis represent 60.8 per cent of the total expense of repairs to road engines, and repairs to passenger locomotives would represent 39.2 per cent of the total repairs to road locomotives. It was found above that repairs to road engines constituted 85.6 per cent of total locomotive repairs. The other 14.4 per cent is switching locomotive mileage which has previously been assigned 90 per cent to freight and 10 per cent to passenger service. Of the total, these figures show 65% is chargeable to freight and 35% to passenger service.

26.-Renewals - Locomotives.

27.-Depreciation - Locomotives.

These two accounts will be affected in the same proportions as previous account, #25, "repairs to ~~road~~ locomotives."

31.-Passenger Train Cars - Repairs.

32.-Passenger Train Cars - Renewals.

33.-Passenger Train Cars - Depreciation.

None of the above three accounts will be appreciably affected by the number of trains.

34.-Freight Cars - Repairs:-This is one of the largest single items to be considered. An analysis of the cost of repairs to freight cars is difficult. No statistics are available to show the distribution of repairs on our railroad. It has been determined by certain other railroads keeping such records that about 20 per cent of the cost of repairs are repairs to underframe, drawbars and brakes. These are the only items which would be materially affected by the number of trains to handle a given tonnage. By decreasing the length of trains or increasing the number, we may expect some saving due to decreased average draw bar pull, and decreased total impact on sills and draw bars due to sudden starting or stopping of train. On the other hand, if we consider the tractive effort of the locomotive to be the same, regardless of the number of trains, these apparent savings will be practically offsetted by the increased strains due to the greater momentary draw bar pull, which is the greatest destructive agent. Experience with the Mallet type of engine has proved that the car repairs will be increased by longer trains, however, due to the fact that in setting and releasing the air brakes the brakes do not act in unison, causing unequal pulls on frame and drawbars. That the e repairs are thus made greater is due to the fact that the draft gear is not designed for such strains. Recent advances in construction are tending to eliminate this to a certain extent, but there are hundreds of thousands of cars with obsolete styles of draft gear which will not stand the strain of long trains, or of the shocks incident to starting a train with one of these big engines.

To offset any saving which might be made by decreasing the length of trains, we have the repairs on an additional caboose, as well as the interest on the same, which is a maintenance charge. In the fiscal year 1910 the caboose cars represented 1.7 per cent of the total freight cars in service. An additional train would require an additional caboose, hence we might figure would increase the repairs to equipment 1.7 per cent of the total cost of repairs to freight equipment. The saving due to decreasing the length of trains will probably not exceed this, hence we may consider the net effects as zero.

35.--Freight Cars - Renewals.

36.--Freight Cars - Depreciation.

Same arguments hold for these two accounts as in repairs to freight cars.

43.--Work Equipment - Repairs.

44.--Work Equipment - Renewals.

45.-Work Equipment.-Depreciation.

These accounts will not be appreciably affected by the length of trains as shown in the consideration of repairs to freight cars. However, they will be affected by the number of trains, as the repairs, etc., will be in proportion to the additional cost of maintenance of way and structures. We found additional train increased cost of maintnance of way and structures expense practically ten per cent. We may assume the same to be true of repairs, etc., to work equipment.

The total charges will be divided between freight and passenger service in same proportion as total for each class of service bears to whole in maintenance of way and structures.

46.-Shop Machinery and Tools.

This account will be affected by additional train in the same percent as the repairs to engines and cars, and total charges will be divided in same proportion as total for each class of service bears to the whole charge for engines and cars.

48.-Injuries to Persons.

While this account is somewhat speculative, it follows a fairly well defined ratio to total charges for repairs and it seems justifiable to assume injuries will increase in same proportions as repairs. We will assume the account as affected in the same proportion as additional pairs to engines and cars, and the total charge will be [illegible]ed in same proportion as total for each class of service bears to the whole charge for engines and cars.

49.--Stationery and Printing.

Will be affected in the same proportions as the account for "shop machinery and tools."

51.--52.--Maintaining Joint Equipment at Terminals.

As the total credit to this account is only .03 per cent of total operating expenses, we will arbitrarily divide it .02 to freight and .01 to passenger service. It will not be appreciably affected by the number of trains.

TOTAL MAINTENANCE OF EQUIPMENT.

The total per cent cost for additional train as indicated by above figures is 5.81% of total operating charge per mile for additional freight train and 3.09% of total operating charge per mile for additional passenger train. It is interesting to make note that Mr. Berry has determined the total additional cost as 7.12% against our 8.90% and against Prof. Webb's estimate of an actual saving of .716%.

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TRAFFIC EXPENSES.

None of the accounts under this head will be affected by additional train, and as accounts are already divided according to freight and passenger traffic no further discussion is necessary.

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TRANSPORTATION EXPENSES.

61.--Superintendence.

62.--Dispatching Trains.

Neither of these accounts will be appreciably affected by an additional train. Division between freight and passenger service will in each case be made according to the train mileage statement.

63.--Station Employes.

(a).--Passenger.
(b).--Freight.
(c).--Telegraph and Telephone Operators.

Increasing the number of trains will undoubtedly increase this account. Local conditions being so different it will, however be principally a matter of using good judgment to determine just what per cent will be affected. Twenty per cent has been estimated by some of the eastern roads. However, on a great many of our own lines in sparsely settled territory there will be no appreciable increase, as the present forces are idle probably half the time. On the other hand we have certain territory which would require as large an increase as figured by the eastern roads. As an average probably fifteen per cent of the time of station employes is devoted to the handling and dispatching of trains and train orders. If the train mileage was doubled a fifteen per cent increase would be required in this work.

The first two items are divided into passenger and freight accounts. The third or (c) will be divided 75% to freight account and 25% to passenger account.

Yard Service.-

This classof service is divided into twelve accounts, all of which will be affected in a greater or less degree by an additional train. The additional expense will consist of terminal delays, handling two cabooses, making up trains on two tracks, with increased amount of switching, and some additional help on account of additional train. None of these items can be very accurately computed and it is again a question of judgment rather than figures as to the per cent which will be affected. In the aggregate, we may say additional train will increase these items 20 per cent. In the table only the increase to the total is indicated as the amount of each item is somewhat speculative. Yard design in general makes it impossible to state with any great degree of accuracy the effect of additional train in these items. If yards are economically handled there will of course be cases where more trains can be handled without any appreciable increase in expense. In very congested yards the making up of an additional train even without any increase in cars may confuse the operation of the entire yard.

In dividing up the separate accounts between freight and passenger service, the car mileage statement is used, as the expense will depend on the number of cars handled, rather than on the number of trains.

ROAD ENGINE SERVICE.

80.-Road Enginemen.

(a).-<u>Passenger</u>

(b).-<u>Freight</u>

81.-<u>Enginehouse Expenses-Road.</u>

Each of the above accounts will evidently be affected 100 per cent by additional train.

Enginehouse expenses will be divided between freight and passenger service on the locomotive mileage basis. In order to make this division accurate, we should have information to show the number of each class of engines handled in and out of roundhouses, but such information is lacking, and the above basis of division is probably not greatly in error.

82-<u>Fuel for Road Locomotives.</u>

(a).-<u>Passenger</u>
(b).-<u>Freight</u>
(c).-<u>Operation of Fuel Stations-Road.</u>

At first glance it might be assumed that an additional train or additional engines would increase the fuel bill 100 per cent,and it has been so considered by the majority of writers on the subject. The error in this assumption is due to not taking into consideration the decrease in tonnage hauled by each locomotive in handling the same tonnage with two engines instead of one.

Experiments by Prof. Goss indicated that twenty per cent of the total fuel consumption performed no function in moving the train, hence is independent of the tonnage. This twenty per cent is consumed in starting fires, in moving the locomotive to its train, in backing trains in and out of sidings, in making good safety valve and leakage losses, and in kee[illegible] [illegible]ne engine hot while standing. Other losses which would be the same in either case, are losses due to head air resistance, radiation and stopping and starting. In the aggregate the items unaffected by tonnage will amount to 50 per cent, according to Wellington. The other 50 per cent he states will vary according to the tonnage ,so that an additional train will affect the fuel bill only 75 per cent.

A study of the writings of Mr. Geo. Henderson on "Cost of Locomotive Operation" indicates these figures are approximately correct for speeds not exceeding 15 miles per hour, which is about the average running speed of drag freight trains. His calculations were, however, based on the locomotive hauling its theoretical rating at the given speed. It is of course seldom in actual practice that this is the case, and an engine will be burning enough coal to be handling more tonnage with practically no increase in fuel consumption. This is especially true in passenger service, for the maximum efficiency in point of tonnage is not the controlling feature in designing passenger locomotives. For this reason we may consider that an additional passenger train would affect the fuel consumption in passenger service practically 100 per cent.

In consideration of the effect on consumption of fuel in freight locomotives by additional train, we will assume 75% is affected, but reservation is make in this statement pending actual tests which it is hoped will be made to determine with more accuracy the actual consumption under the conditions named.

The cost of operation of fuel stations will follow very closely the cost of fuel, and total will be divided between freight and passenger service according to the locomotive mileage statement.

83.-Water for Road Locomotives.

This account will be divided on locomotive mileage basis with assumption that freight locomotives average 25 per cent more water per locomotive mile than passenger locomotives. This is the record of a ninety days' actual test and may be regarded as a good average. Effect of additional train will be same as for fuel.

84.-Lubricants for Road Locomotives.

This account will be affected 100 per cent in each case by additional train, and will be divided according to the locomotive mileage statement.

85.-Other Supplies for Road Locomotives.

In this account is included the paraphernalia needed around engines, such as torches, tools, waste, oil cans, etc., and is increased or decreased in accordance with the number of engines in service, hence would be increased 100 per cent by additional train. The cost probably varies more nearly in accordance with the train mileage than with the locomotive mileage, hence will be divided in that manner.

Train Service.

88.-Road Trainmen:-

(a).-Passenger.
(b).-Freight.

These accounts will be affected 100 per cent by additional train. In case of freight trainmen it might be assumed that decreasing the length of trains would allow of one less brakemen. This, however, is doubtful, as the tendency of the trainmen's union is to demand increases without any decreases.

89.-Train Supplies and Expenses.

(a).-Care of Passenger Cars:-This account would not be appreciably affected by the number of trains.

(b).-Passenger Train Supplies and Expenses:-This account includes items which would all be affected 100 per cent by additional train.

(c).-Care of Freight Cars.
(d).-Freight Train Supplies and Expenses.

Account (c) will not be affected by number of trains. Account (d) will be affected 100 per cent by additional train.

CASUALTIES.

The effect of additional train on this account, will of course be speculative. One thing is certain, however, that the number of wrecks and loss incident thereto, will increase with the number of trains. Theoretically there would be a direct ratio between train mileage and casualties. By going back over several years's records we could derive a relation between train mileage and this account for both freight and passenger service. The results would hardly justify the expense as the account is not large. As there are some items in the account which could not bear any relation to the train mileage, it will be arbitrarily assumed that an increase of 50 per cent will be caused by additional train.

MISCELLANEOUS.

Under this account item 94.-(Telegraph and Telephone Operation) would be affected 15 per cent as decided in account 63.-c, and would be divided 75 per cent to freight and 25 per cent to passenger service. Stationery and printing expenses will be assumed as affected 50 per cent and divided 75 per cent to freight and 25 per cent to passenger service. As all of these items are small any error in judgment in determining the per cent affected will be inappreciable. The remaining items of this account will not be affected by number of trains run. They will all be divided according to the train mileage statement.

TOTAL TRANSPORTATION EXPENSES.

The total per cent cost for additional train as indicated by above figures is 20.20% of total operating expenses per train mile for additional freight train and 10.03% of total operating expenses per train mile for additional passenger train. It is noted Mr. Berry has determined the total additional cost as 28.57 as against our total of 30.23, and as against Prof. Webb's estimate of 41.972. As nearly as it is possible to separate Mr. Wellington's figures he has estimated Transportation Expenses would be affected 27% per cent by additional train.

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GENERAL EXPENSES.

None of the items under this head would be appreciably affected by additional train. An arbitrary division of the total will be made, charging 75 per cent to freight and 25 per cent to passenger service.

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TAXES.

Taxes will not be affected by the number of trains. Division will be made according to the total income account figures.

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SUMMARY AND CONCLUSIONS.

A summation of the various accounts shows that of the total operating expenses 69.23% are charged to freight and 30.77% tp passenger service.

In determining the per cent cost for additional freight train, it is found that 27.46% of the total operating expenses will be increased by additional train. However, this 27.46% is equal to 39.7 per cent of the cost per freight train mile, hence an additional freight train will cost 39.7% of the cost of operation per freight train mile. As previously given, the total operating expenses for the fiscal year 1910 were $30,135,028.15. The total cost then, of freight operation was 69.23% of this amount or $20,862,-479.98. Total freight train mileage as previously given was 13,142,717 miles. In other words, the operating cost per freight train mile was $1.58.

Below is given a table compiled from Auditor's #504 report, showing operating expenses per freight train mile for each month of the fiscal year ending June 30th, 1910. Figures are in cents per train mile. Also same data for year 1911.

Month.	Fiscal Year Ending June 30th, 1910.	Fiscal Year Ending June 30th, 1911.
July	153.67	145.96
August	157.88	149.33
September	156.58	153.98
October	165.97	161.53
November	169.59	176.43
December	162.64	162.38
January	141.18	159.77
February	144.34	161.76
March	130.72	153.45
April	138.92	164.61
May	136.63	161.82
June	134.54	151.16
Average Cost	149.39	158.52

To the average cost for the fiscal year ending June 30th, 1910, should be added 7.7 cents per train mile for taxes, bringing the total to $1.57 per train mile as compared to the estimate we have made of $1.58 per train mile from the annual report.

An additional freight train as stated above will cost 39.7% of $1.58 or $0.627 per train mile.

In determining the per cent cost per additional passenger train mile, it is found that 13.66% of the total operating expenses will be increased by additional train. This 13.66% is equal to 44.4% of the cost of operation per passenger train mile. The total operating expenses for passenger mileage were found to be $9,272,548.17, and the total passenger train mileage was 10,300,337 miles, or the cost of operation per passenger train mile was $0.90. An additional train affecting 44.4% of this amount would cost $0.40 per train mile.

For comparison with the results worked out by other engineers, the additional cost per train mile not separated as to freight and passenger service might be interesting. It was found that the total per cent affected by additional train is 41.12%. In the first part of the discussion the average cost of operating expenses per train mile was found to be $1.29. The average cost per additional train mile from these figures would be $0.53.

In a report to Mr. Gray in 1907, Mr. C. D. Purdon, then chief engineer, stated 42.23 per cent of operating expenses are affected by additional train mileage.

In reducing grades on the Union Pacific Railroad, Mr. Berry estimated 43,29% of operating expenses as affected by the train mileage.

Prof. Webb estimated 44.79% affected and Mr. A. M. Wellington estimated 47.8% affected by the train mileage.

The writer believes that the reason all these engineers were on the safe side in their calculations is due to the fact that the average cost of operation is less than the cost of operation of freight trains.

As an engine must be returned for each engine going over a division in order to effect any saving by grade reduction, the number of trains saved in one direction must also be saved in the opposite direction. Or, in other words, for each mile of track there must be two train miles saved. It would possibly be better to say two engine miles must be saved, as cases are possible where light engines must be run one way to handle a traffic, while after the grade reduction the light engine mileage would be saved in one direction and loaded engine mileage in the other direction.

To make rough calculations as to savings, time card ratings and regular trains from the time card together with approximate number of extras, may be used. For example assume a case on the Northern Division of the Frisco, from Kansas City, Mo., to Fort Scott, Kas., a distance of 99 miles. There are at present five regularly scheduled freight trains each way per day, besides the Missouri, Kansas & Texas trains, and local freights. How much money would the Frisco be justified in spending to reduce the number of trains to four regular trains each way per day? This would be a saving of two train miles per track mile. We found a freight train mile saved represented a saving of \$0.627. Two train miles saved each day over a 99-mile district for one year would represent a saving of

$$2 \times \$0.627 \times 99 \times 365 \times 1 = \$48,926.80$$

This amount capitalized at 5% interest is equal to \$978,536.00, or the amount which could be justifiably spent to make such reduction in the number of trains.

If in reducing the grades in order to make such a reduction in the number of freights trins, there should be a reduction possible in the number of passenger trains we could apply our figures derived for saving in passenger train mileage and the total of the two would be the amount which could be justifiably spent. As before satted there will be very few cases where the passenger train mileage can be reduced by grade reduction, although some of the minor savings in distance, etc., will of course reduce the cost of passenger train operation.

All of the calculations have been based on the average cost of operation for the entire Frisco System. In case greater refinement is desired, the cost of operation on the division in question should be determined by applying the per cents affected to the various expenses chargeable to that particular division. The Auditor's 501 report shows the expenses for maintenance of way and structures, and the transportation expenses for each division on the system. The expense of maintenance of equipment and general expenses are not subdivided for the different divisions, and it is probably accurate enough for any estimate to divide these expenses according to the train mileage figures. Very accurate figures for reduction of grade on any particular division may thus be found. However, it has been found that the cost of operation on the different divisions does not vary greatly, regardless of the grades, in so far as the minor amounts are concerned. Wages of trainmen, etc., are approximately the same on all divisions. A glance at the tonnage rating of the same class of engines on different divisions shows at once, however, that the cost per car mile on different divisions will vary greatly with the same amount of business offered.

The question is naturally asked in grade reduction investigations, why the tonnage cannot be increased per train mile by increasing the tractive effort of the locomotives instead of reducing the grades. This of course is being done by a great many roads, including our own, but the fact remains that the cost of operation is increasing rather than decreasing. There are a number of objections to the too great increase in the size of motive power. There is also always the fact remaining that no matter how large the locomotive, it can haul more on a level grade than on any ascending grade, hence the size of the locomotive is not the limiting feature of economy. As to the heavier locomotive vs. the same amount of money spent in grade reduction we have the following facts to consider. In the first place a great deal of the power of a locomotive is wasted. If made heavy enough and large enough to haul say sixty cars on a plus five-tenths per cent grade, all the power utilized on level track and on descending grades, in excess of that in an engine capable of hauling say forty cars on a plus five-tenths per cent grade would be wasted, for the lighter engine would do the required amount of work on level or descending grades, or grades lessthan the maximum with less fuel consumption, with less cost of repairs and actually with less wages for enginemen and crew. The time on the road is necessarily longer with the heavier engine. While the actual running time may not be greatly different more time is consumed in meeting points, unless the track is in the best of condition the running time has to be reduced, etc. We find greater amount of fuel burned on account of radiation, fuel burning which is not going into hauling the train, etc. It has been stated on our particular railroad that the fuel consumed per ton mile was about one-third less with a Mallet engine hauling its maximum tonnage than with the 1200 class engine with about half the tonnage. If the writer is not mistaken, the increase in interest charges on these engines is much more than the saving in fuel. Congestion in traffic is caused by too long trains, unless there are a very great number of trains. To show the effect of this on operating expenses, we might imagine an extreme case in which all the freight hauled over a division was hauled in one train. Most of the day the terminals would be empty and the engines and yard crews not working. Then when this one monster train comes in, a big force must be put to work breaking it up and switching it so it can be gotten out on the various divisions to which it is consigned, without long delays. In order to balance the working of the terminals, the cars must come and go with great regularity. Otherwise during part of the day everyone isidle and the rest of the day everything is confusion, cars are damaged by rough handling, injuries are increased and with all these things operating expenses increase. What is true of the terminals is true in a greater or less degree of the remainder of the division.

Another item to be mentioned is the necessity for increasing the length of passing tracks, due to the longer trains. The number must usually be increased at the same time due to the slower movement and greater number of meeting points with faster trains. The same will of course be true to a lesser degree after a grade reduction, when the length of trains will be increased, and in many cases the average speed decreased. It is true that in the former case the number of trains will be reduced at first, but additional tonnage will require more power, and in a much greater ration in the majority of cases to the increase in tonnage than would be required after grade reduction. The interest charges on the larger engine will also be increased, and unless full tonnage is handled at all times this charge will greatly increase the cost per ton mile and tend to offset any saving in fuel and wages.

Another vital objection to the increase of the size of motive power instead of grade reduction is the fact that engines rarely handle their full tonnage throughout a run. The result of course is, that for the greater part of the run coal xx consumption is greater than necessary, wages oil, water etc. greater than necessary, simply because the road has replaced its light power with heavy and must therefore haul its trains with heavier power in a vast number of cases than is required. To the practical man this point is very clear, and the analysis of any month's train sheets will show this to be the case. For example, a complete analysis of the freight movement on the Northern Division of the Frisco for a year's time, showed that the average per cent of rating handled varied from 41.4% to 79.2% of the time card rating, which was practically the theoretical rating, and that in only one month was the tonnage actually handled over 90% of the rating of the engines. The reasons for this were manifold. Light engines had to be moved in order to balance the engine mileage. Merchandise had to be moved at stated times rather than wait for full tonnage. Trains had to be timed for certain meeting points, etc.

Another objection to the tendency to increase the weight of locomotives, is the necessity for improvements in sub-structure of track, more ballast, heavier rails, and stronger fastenings. Not very many years ago ten or twelve inches of rock ballast under the ties was considered the limit of economy in ballasting. But in recent years eighteen to twenty-four inches is recommended to hold the track in surface, and all this principally on account of the increase in size of motive power.

Rail weighing 75 pounds to the yard was once thought to be the practical limit to the weight of rail, but now the manufacturere are making rail weighing 110 pounds per yard to hold up with safety the large engines in service. The first cost of this increase in the amonnt of ballast, in the sixe of rail and weight of fastenings is being charged to the capital account, but the interest on such increased cost is charged to interest on funded debt, which in reality should be considered as a part of the expense of maintenance of way. The renewals of these items are in fact charged to maintenance and if we look at the statement of average cost per mile for several years back, it is at once apparent that the cost per train mile is increasing faster than the increse in tonnage would seem to warrant.

Add the first cost of the increased weight of rail ballast and fastenings, the increased cost of the heavier locomotives, and an amount of capital which represents the increased maintenance charges due to renewing and maintaining the heavier rail, ballast, engines etc., and subtract therefrom any savings due to operating the heavier locomotives, and compare the total to the cost of reducing the maximum grades an amount sufficient to permit the lighter engines to handle the same tonnage as the heavier engines, and it is believed in ninety-nine cases out of every hundred the grade reduction will be the more economical. And it will at the same time put the road in shape to handle its increased business for some time to come.

There is given under the head of "Locomotive Tractive Power" the results of a 30 days test covering the cost of performance of engines 1301 and 2006, the latter being a Mallet articulated type with practically twice as much weight on the drivers as engine 1301, and twice the tractive power. The results of this test, which included only the transportation expense and maintenance of the locomotive, showed that engine 1301 was actually operated $.02 per ton mile cheaper than engine 2006. The comparison is faulty in that neither engine hauled its rating, and the figures indicated that engine 2006 could be operated about $.01 per ton mile cheaper than engine 1301, if the latter as well as the Mallet had handled their full rating, this figure applying only to such charges as were considered in the test and mentioned above. The net cost of operation for the fiscal year was approximately $.10 per ton mile. Assume for a moment that the weight of all engines was doubled, thereby saving $.01 per ton mile on all freight handled, or about 10 per cent of operating expenses. This would represent a total saving for the year of approximately $3,000,000. On the other hand, it is not an unreasonable assumption to say that to double the weight of engines would necessitate increasing the depth of ballast six inches, the weight of rail 15 pounds per yard, and fastenings in proportion, and also strengthening the bridges and increasing the track labor, in order to maintain the same standard of maintenance and efficiency. The increased yearly charge to maintenance would thereby be roughly $600 per mile or $3,000,000 per year, just about ofsetting the saving by increasing the weight of the engines, provided they handled their full tonnage. However, as the test showed and as has been stated above, the per cent of rating handled usually decreases with the increase in weight of locomotives, with the result that the saving in operating expenses is less than the increased cost of maintenance of way.

While the above statements have not been worked out in great detail and possibly not all points considered, they show in a general way that no great saving is to be expected from doubling the weight of engines to haul the same traffic, and that even if some saving results, their use must in the long run be supplemented by reduction of grades in order to increase the tonnage rating of the engines in use. If the interest and depreciation on the increased cost of the heavier engines was applied as interest on money necessary for grade reduction, and presuming the same saving in transportation expenses could be made with the present engines after such grade reduction, about $20,000,000 could be expended for the grade reduction without increasing the expense to maintenance of way.

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DISTANCE--ITS EFFECT ON OPERATING EXPENSES.

If railroad companies were allowed to charge rates such that they would earn a fixed per cent on their investment, and there were no competing lines, it would obviously be to their advantage to cut all the summits and fill all the sags and construct their lines as nearly straight as possible. The only limit of expenditure would be in the amount of capital which might be controlled. Under actual conditions this is not often possible, and we find that rates have in most cases been made on the basis of length of haul, rather than any profit on the investment.

The building of competing lines makes it necessary for all the roads to charge through rates in accordance with the lowset rate, in order to get an equal share of the business offered. The local business will of course not be affected by competing lines, unless through the same towns.

Freight and passenger revenue and expenses will be affected in different proportions and should be considered separately.

It is evident that short changes in length of line will not affect the operating freight revenue, as freight rates are not strictly on a mileage basis, although the distance usually determines the rate in a large measure. Changes in distance amounting to miles may causes changes in the rate on freight, but small changes, even of one or two miles, will as a rule not affect the rate at all.

Any reduction in the length of line will, however, reduce the operating expenses. Small reductions in distance, amounting to feet, or reductions so small as not to affect trainmen's wages, will reduce the operating expenses less than distances great enough to affect trainmen's wages.

In consideration of the effect of reducing distance as affecting operating revenue from passenger business, the conditions are slightly different. Passenger revenue is almost entirely on a strictly mileage basis. Through rates will still be dependent on the length of the shortest line, however. For instance, the Missouri Pacific Railroad has the shortest line between Kansas City and St. Louis, hence fix the rate between these points. Passenger conductors and brakemen are paid on a monthly salary basis, hence except in extreme changes in length of line will still be paid on the same schedule. Passenger engineers are paid on basis of 100 miles minimum with additional pay for additional mileage. Hence, any reductions in distance on a division of over 100 miles would decrease their wages, while any reduction in distance on a division of less than 100 miles would not affect their wages, unless the reduction was so great as to affect their schedule.

In determining the effect of distance two points should then be remembered:-

First-the reduction in operating revenue, and second the reduction in operating expenses. The reduction in operating revenue will be more or less a speculative quantity, and should be considered for each locality as a separate proposition. The reduction in operating expenses can be determined with some degree of accuracy and is the problem in hand.

Below is given a statement showing the per cent cost of small and large increases in distance as affecting the different items of operating expenses. These items are the same as given in statement showing the additional expenses due to increasing the train mileage, and for the sake of brevity only the items affected are listed. From this statement we may arrive at the saving to be effected by reducing the distance by a small or large amount. It must be understood that in arriving at the results indicated, average conditions as nearly as possible are assumed. In consideration of a concrete case, the items may be affected in different proportions from that shown, hence each case depending on its importance should be considered separately in arriving at values. The statement is for convenience divided into three classes, as follows:-

1.-Small distances not affecting the wages of trainmen or enginemen.

2.-Distances great enough to affect the wages of trainmen or enginemen, but not great enough to require additional side tracks or stations.

3.-Distances great enought to affect the wages of trainmen and enginemen, and to require additional side tracks and stations.

By means of this division the results may be derived with greater accuracy, and made applicable to the majority of cases which will arise.

Following the statement is given a brief outline of the basis of determining the figures indicated.

Increase in Distance and Its Effect on Operating Expenses.

FREIGHT SERVICE.

Class -	% Whole	Proportion Affected Perct 1	2	3	% Cost Per Add'l Train Mile 1	2	3
2-Ballast----------	.68	90	90	95	.61	.61	.65
3-Ties------------	3.21	90	90	95	2.89	2.89	3.05
4-Rails-----------	.38	90	90	95	.34	.34	.36
5-Other Tr. Mat'l	.62	90	90	95	.56	.56	.59
6-Roadway & Track	4.26	90	90	95	3.83	3.83	4.05
7-Removal Snow and sand and ice---	.03	90	90	95	.03	.03	.03
11-Grade Xingsetc	.24	100	100	100	.24	.24	.24
13-Signals and Interlocking----	.11	00	00	100	00	00	.11
14-Telegraph and Telephone lines	.21	90	90	95	.19	.19	.20
16-Bldgs, Fixt and Grounds---------	.43	00	00	100	00	00	.43
18-Roadway Tools and Supplies---	.23	90	90	95	.21	.21	.22
25-Steam locomotive repairs, Etc---	5.23	38	38	53	2.00	2.00	2.77
34-Freight car repairs, etc.---	6.70	27	27	45	1.81	1.81	3.02
43-Work Equipment, repairs, etc.,	.14	27	27	45	.04	.04	.06
46-Shop machinery and tools-------	.38	27	27	45	.10	.10	.17
48-Inj. to Persons	.09	27	27	45	.03	.03	.04
Forward--							

Freight Service-Continued.

Class---	% Whole	Proportion Affected Perct 1	2	3	% Cost Per Add'l Train Mile 1	2	3
49-Stat. & Printg	.03	27	27	45	.01	.01	.01
63-Station Employes	5.04	00	00	80	00	00	4.03
66-Station Supplis and expenses---	.33	00	00	80	00	00	.26
80-Road Enginemen	4.48	00	100	100	00	4.48	4.48
82-Fuel for road locomotives---	6.64	50	50	65	3.32	3.32	4.32
82-c-Operation of fuel sta-road-	.19	50	50	65	.10	.10	.12
83-Water for road Locomotives---	.49	50	50	65	.25	.25	.32
84-Lubricants for road locomotivs	.15	30	30	80	.05	.05	.12
88-Road trainmen,-freight,-------	5.43	00	100	100	00	5.43	5.43
Casualties-Total	2.63	50	100	100	1.32	2.63	2.63
Taxes---------- --	3.31	5	5	16	.16	.16	.53
Total---------	51.66				18.09	29.31	38.24

PASSENGER SERVICE.

Class-----	% Whole	Proportion Affected Perct 1	2	3	% Cost per Add'l Train Mile 1	2	3
2-Ballast--------	.54	90	90	95	.49	.49	.51
3-Ties-----------	1.23	90	90	95	1.11	1.11	1.18
4-Rails----------	.14	90	90	95	.12	.12	~~1.18~~ .13
5-Other track matl	.22	90	90	95	.20	.20	.21
6-Roadway & Track	1.89	90	90	95	1.70	1.70	1.80
7-Removal snow, sand and iee---	.02	90	90	95	.02	.02	.02
11-Grade Xings etc	.18	100	100	100	.18	.18	.18
13-Signals and Interlocking,---	.08	00	00	100	00	00	.08
14-Telegraph and telephone lins	.17	90	90	95	.15	.15	.16
16-Bldgs, Fixt and Grounds,------	.19	00	00	100	00	00	.19
18-Roadway tools and Supplies	.10	90	90	95	.09	.09	.10
25-Steam Locomotives, repairs	3.37	38	38	53	1.28	1.28	1.79
31-Passenger cars Repairs, etc.	1.54	35	35	45	.54	.54	.69

Forward-----

Passenger Service-Continued.

Class----	% Whole	Proportion Affected perct.			% Cost Per Add'l Train Mile		
		1	2	3	1	2	3
43-Work Equip-Rep	.08	27	27	45	.02	.02	.04
46-Shop machinery and tools,----	.15	35	35	45	.05	.05	.07
48-Injuries to persons,---------	.03	35	35	45	.01	.01	.01
49-Stat. & Printng	.01	35	35	45	00	00	00
63-Station Employes	1.06	00	00	00	00	00	.85
66-Station supplies and expenses	.11	00	00	00	00	00	.09
80-Road Enginemen,	2.36	00	00	100	00	2.36	2.36
82-Fuel for road locomotives	2.85	50	50	65	1.43	1.43	1.85
82-c-Operation of road fuel statns	.12	50	50	65	.06	.06	.08
83-Water for road locomotives,---	.21	50	50	65	.10	.10	.14
84-Lubricants for road locomotivs	.09	30	30	80	.03	.03	.07
Casualties-Total	2.06	50	100	100	1.03	2.06	2.06
Taxes,------------	1.43	5	5	16	.07	.07	.23
Total--------------	20.23				8.68	12.07	14.89

The total mileage of the Frisco Lines in 1910 was as follows, the proportion of the last two items to the total being estimated:-

Main track - - - - - - - -	5112 Miles.
Sidings - Large Terminals	732 "
Sidings - Small Terminals	732 "
Total- - - - - -	6576 Miles.

Experience has shown that about one-third as much work is spent on side tracks as on main track. On this basis the maintenance of way and structures charges as applying to main and side track would be divided as follows:-

Main track	90	Per Cent
Sidings-Large Terminals	5	" "
Sidings- Small Terminals	5	" "
Total	100	Per Cent.

In considering the first two classes of increase of distance, as above divided, the maintenance charges to all track but main track should be neglected, as only the total mileage of the main track will be affected by the increased distance. In case of third class the total mileage will obviously be affected in some per cent, as shown later.

2.-Ballast:-As teh maintenance of ballast will, obviously depend on the length of line, 90% of the total would be affected by increasing the distance in the first two classes and 95% in last class, as large terminals would not be affected appreciably.

3.-Ties:-The number of ties which have to be renewed each year will depend on the distance, hence by doubling the distance the cost of tie renewals would be doubled, or 90% of the whole would be affected in first and second class of increase in distance and 95% in third class.

4.-Rails:-Same is true of rails as of ties.

5.-Other track material:-Same is true as of ties.

6.-Roadway and Track:-This account was divided into nine sub-accounts, "Changing alignment and grades", "Flood Damage,""Bank Protection," and "Filling" all of which accounts may be affected in specific instances, but which should not be considered as affected in general. The remainder of the account will be affectod in the same proportions as ties.

9.-<u>Bridges, Trestles and Culverts</u>:-This account may or may not be affected according to the particular location. As it is therefore speculative, it will not be considered.

11.-<u>Grade Crossings, Fences, Signs, etc</u>:-As the maintenance on these items will depend directly upon the length of line, the account will be affected 100 per cent by doubling the distance.

13.-<u>Signals and Interlocking</u>:-The first two classes of distance would not affect this item appreciably, but the third class would affect it 100 per cent.

14.-<u>Tolegraph and Telephone Lines</u>:- If we consider the maintenance chargeable to this account to be in the same proportion as track, increase in distance not great enough to increase the number of side tracks or stations would affect the first two classes of distance 90%. Increases in distance great enough to increase number of side tracks and stations would increase the account 95% ordinarily and possibly 100 per cent in special cases.

16.-<u>Buildings, Fixtures and Grounds</u>:-This account, it will be remembered, was sub-divided as follows:

A-Transportation Buildings.
B-Fuel and Water Stations.
C-Shops, Enginehouses and Turntables.
D-Other Buildings.

It is evident that changes in the first two classes of distance would have no effect on any of these items. The third class would affect sub-item "A" 100% and in some cases might affect any of the four sub-items. As the last three are uncertain, only the first will be considered.

18.-Roadway Tools and Supplies:-As only 90% of maintenance of track is chargeable to main track, any increase in distance not affecting side tracks would affect 90% of the expense of roadway tools and supplies. In case the number or length of side tracks was increased by increasing the number of small stations, there would be 95% affected.

25.-Steam Locomotives-repairs, renewals and depreciation:-If repairs to locomotives were entirely dependent on the distance run, we could easily determine the effect on the account by increasing the distance. However, as will be found, less than half of the repairs are affected by the mileage made. The contributing causes of repairs are age, starting and stopping, terminal work and getting up steam, average curvature, grades and distance.

Mr. Wellington was probably one of the most careful investigators on the distribution of these items. A table prepared by him is given below:-

Distribution of the Cost of Engine Repairs to Its Contributing causes.--By A. M. Wellington.

ITEMS.	Total Cost Per Cent	Time, Age & Exposure.	Stopng & Starting at Way Stations.	Terminal Delays-Firing Up, etc	Curvature. Approximate Averag	Distance on tangent between Stations
Boiler	20.0	0.00	2.00	7.00	4.00	7.00
Running gear	20.0	0.00	4.00	2.00	7.00	7.00
Machinery	30.0	1.00	7.00	3.00	5.00	14.00
Mountings	----	----	----	----	----	-----
Lagging and Painting,	12.0	4.00	----	2.00	----	6.00
Smoke box, etc	5.00	1.00	----	1.00	----	3.00
Tender-------						
a.-Running gear	10.0	----	2.00	1.00	3.00	4.00
b.-Body & Tank	3.0	1.00	----	1.00	----	1.00
Total------	100.0	7.00	15.00	17.00	19.00	42.00

These figures were of course gotten up several years ago, and conditions have changed somewhat. Unfortunately the records today are not kept in such detail that Mr. Wellington's figures can be given an accurate check. Such data as we have indicates between 38 and 40 per cent of repairs may be charged to the ordinary wear and tear of hauling the train, or as given in the last column of the table, to "distance on tangent between stations." Electric headlights, air brakes, the Walschaert valve gear and other refinements added to the engine, all of which contain many intricate and expensive parts, have raised the per cent cost of the other items, thereby lowering the per cent cost affected by distance without lowering the cost itself. The writer is therefore inclined to use the figure of 38 per cent.

Stopping and starting at way stations is estimated by Mr. Wellington to cause 15% of repairs. This figure is probably very nearly correct and will be accepted.

In increasing the distance by classes one and two we would then expect an increase of 38 per cent and in increasing the distance by class three we would find repairs, etc., increased by 53 per cent. It must be remembered, however, that only repairs to road engines will be affected. It has been previously determined that 8.60 per cent of toal operating expenses were chargeable to repairs to road locomotives, of which total 60.8 was chargeable to freight service and 39.2 per cent to passenger service.

31.—Passenger Train Cars—Repairs, Renewals, Depreciation:—Figures at present available indicate that about 35 per cent of car repairs can be charged directly to the distance on tangent while running. Stopping and starting at stations, other than terminals causes about 20 per cent of repairs, time and exposure about 8 per cent, terminal switching and making up trains 15 per cent and curvature and grades 22 per cent. It would be very difficult to make an absolutely accurate separation of the contributing causes, and our information may not be entirely correct. The only way such figures can be derived is to separate the items of repairs and their cost and then determine as accurately as possible the effect of the various contributing causes to each item of repair.

Renewals and depreciation will follow practically the same separation as the repairs, being dependent on the same contributing causes.

We may then figure that in the first two classes of increase in distance 35 per cent of passenger car repairs will have to be added in doubling the Distance, and in the third class, where the number of stops must be considered we should add to this 35 per cent the cost per cent of making the additional stop. About half the passenger trains are locals, which might be required to stop at additional station, hence 10 per cent, or a total of 45 per cent will be affected orincreased in increasing the distance by the third class.

34.-Freight Cars-Repairs, Renewals, Etc.;-This account should be considered in the same manner as the repairs to locomotives and passenger cars, There is one contributing cause in freight car repairs which does not seem to have been given the proper consideration by any of the prominent investigators on the subject of grade reduction. This is the per cent of repairs due to loading and unloading of freight. Careless loading sends thousands of freight cars to the repair yards yearly. Doors are broken off, sides stove in by lumber shipped in box cars, floors are torn up by spiking heavy machinery to them, etc. All these items of course form a part of the so-called natural deterioration of the car, but they are independently a factor in car repairs. The most accurate figures at hand indicate that about 10 per cent of the total cost of repairs are caused by loading and unloading. Of the remainder about 30 per cent may be charged to distance between stations on level tangent, being ordinary wear and tear, stopping and starting at way stations 20 per cent, terminal switching in making up trains about 25 per cent, time and exposure 10 per cent, and curvature and grades 15 per cent. Thus distributed the total cost of repairs would be as follows:-

Loading and unloading	10 %
Distance on tangent	27 %
Starting and stopping at way stations	18 %
Terminal switching	22.5 %
Time and exposure	9 %
Curvature and grades	13.5 %
Total	100.0 %

The per cent of total cost of repairs affected by increasing the distance by first two classes would then be 27 per cent, and for the third class 45 per cent.

43.-Work Equipment:-The figures applicable to freight car repairs will apply without great error to work equipment. From the nature of the service the repairs due to loading and unloading will probably be considerably larger, and there will be less starting and stopping and less switching at terminals. As the account is very small compared to the whole, the error in assuming the same division will be inappreciable.

46.-Shop Machinery and Tools:-This account should obviously be affected in same proportion as repairs to different classes of equipment and is so considered.

48.-Injuries to Persons:-
49.-Stationery and Printing:-

These items will be considered as affected in same proportion as repairs to different classes of equipment.

63.-Station Employes:-There would of course be no increase in this item where there was no increase in the number of stations, hence the first two classes of increase in distance would not affect this account. In the third classs the increase would depend to a large extent on the size of the station, and whether one man could perform all the duties of agent and operator. When the additional track and station were first added the agent might not be necessary. To assume an average condition it seems justifiable to say that the station would be a one man station, or that about 80 per cent of cost of station employes would be affected.

66.-Station Supplies and Expenses:-This account would be affected the same as account #63.

Yard Service-General:-This account includes all the items of operating expenses which are incurred in a terminal in the switching of cars into trains, placing cars at industries for loading and unloading, and the supplies and expenses incident to the work. For small changes in distance and even for distances amounting to several miles, there will be no effect on the yard expenses. It will be only when the distance is great enough to require the addition of equipment that there will be any increase in yard service. As none of the classes of distance with which we are dealing approach this amount we may consider the effect of increase in distance on yard operation to be mothing.

Road-Engine-Service:-This division of operating expenses is made up of wages of enginemen, fuel for locomotives, water, oil and other supplies used on road engines.

80-Road Enginemen:-As already stated, engineers are paid on a basis of 100 miles. If less than 100 miles is run, the pay is for 100 miles. If more than 100 miles is run, the amount due is increased in proportion to whatever per cent of 100 miles is added and on the basis of 100 miles pay. Pusher service is based on 10-hour day. Switch engine and work train service is based on 10-hour day. Switch engine service does not enter into our figures, however, and work train service is charged to another account. Branch line service is paid both on the 100 mile basis and on the 10-hour service. Due Consideration would have to be given this feature in consideration of the question of grade reduction as applied particularly to branch lines.

With these facts in mind, there must evidently be a division into two classes. If the mileage of the division is less than 100 miles, any increase in distance which leaves the total mileage less than 100 miles will not affect the pay of engineers. If a division is over 100 miles, any increase in distance less than one mile, or such that the engineer is not paid for an additional mile, will not increase the engineer's pay. Any increase measured in miles will of course increase the pay on the mileage basis.

To show that small increases in distance may affect the pay on a mileage basis, it must be remembered that the pay is according to the nearest mile. For example, a division 125.3 miles in length is paid on pasis of 123 miles. If .1 mile was added the pay would still be on the 125 mile basis, but if .2 or .3 mile was added the pay would be on the 126 mile basis. For this reason the total distance must always be kept in mind instead of assuming that it will take .5 mile or more to increase the pay to the mileage basis.

On the Frisco Railroad there is only one engine division of less than 100 miles, this being Kansas City to Fort Scott, 98.6 miles. For the purpose of this discussion it may be assumed that any change adding to the mileage as figured to the nearest mile, will affect the pay of enginemen.

Firemen are paid on the same kind of schedule as the enginemen, or engineers, so their wages will be affected in the same proportion.

By increasing the distance according to the first class in which trainmen's wages are not affected we would of course add nothing to this item of operating expenses. If the distance be increased by either of the last two classes the increase would of course be 100 per cent.

81.-Enginehouse Expenses-Road:-This account will not be affected except for great increases in distance requiring additional motive power. This can hardly be conceived, as such increase would probably result in increasing the number of divisions. It would of course be possible to increase one division sufficiently to require additional freight cars, by reason of an increased business coming from a larger territory.

82.-Fuel for Road Locomotives:-As has already been touched upon, a considerable portion of the fuel consumed performs no work in moving the train forward. The amount of fuel consumed by engines standing at terminals waiting for trains has increased in the last few years, due to the practiceof not drawing the fires, but of cleaning and banking them and later sending the engine out on another run. Against the expense of this practice are two savings, the saving in the large amount of fuel necessary to get up steam, and the saving in boiler repairs due to less expansion and contraction. The saving due to banking the fires will depend on how long the engine is kept standing, and in the end may result in more coal consumption than would be necessary in firing up a cold engine.

In general the contributing causes of fuel consumption are as follows:-Firing or getting up steam, radiation, starting and stopping, grades, curvature and distance. To these might be added the personal equation of the fireman as there is undoubtedly lots of bad firing, resulting in immense losses of fuel shot out throughthe stack without burning. On every trip the per cent each item bears to the whole will evidently vary. Hence, to say definitely what per cent of the fuel bill should be charged to actually moving the train forward is impossible. Different classes of engines will burn different amounts of coal per ton mile, long and short runs will change the per centages, so that in the end we would expect a great variation of figures.

The average of operating conditions will in such case be required in order to give the best average figure, which for ordinary estimates will be sufficiently accurate. Specific cases may require tests for comparative purposes.

Our fuel department records show that 24% to 26% of the total coal consumption occurs with the engine standing, and 74% tp 76% while running. They also show on the divisions with moderate rise and fall that the rise and fall and curvature are the cause of about 30% of the fuel consumption as compared to the performance of the same engines under similar conditions on divisions with practically no rise and fall. By reducing the total curvature to feet rise and regarding it as a part of the total rise and fall, it is found that for the system as a whole the fuel consumption due to average curvature would be approximately four per cent.

Prof. Webb has prepared a table which is given below, indicating the high and low per cents which may be ascribed to eac h contributing cause.

Firing ----------------------	5	to	10	per cent.
Loss by radiation ------------	3	to	6	" "
Stopping and starting --------	10	to	20	" "
Average curvature ------------	4	to	4	" "
Average grade ----------------	25	to	25	" "
Direct hauling ---------------	53	to	35	" "
Total ---------	100	to	100	per cent.

Average directly due to distance as indicated by this table would be 44 per cent.

Wellington estimated that two-thirds of the fuel used is actually consumed in moving the train forward, and the other third is loss by firing, radiation and while standing. This estimate agress fairly well with the figures prepared by Prof. Webb, showing however a somewhat greater loss of fuel not available for moving the train.

In a test covering two Frisco engines on 49 trips over an engine district of 140 miles, a statement was compiled showing that 75.5 per cent of the total coal used with one engine and 79.5 per cent of the total coal used with the other engine was actually used in the direct hauling of the train, that is w hile running. This agrees very well with the averages given in the above table. We have no very accurate record, however of the amount of coal burned on account of the grades or rise and fall encountered, and can only arrive at this by comparing the performance of the same engines on divisions with practically no grades. From tonnage t tests made on the Eastern Division with its very heavy rise and fall and grades, and on the River Division between Chaffee and Hayti, with a practically level grade, it was found that where 80 pounds of coal per 1000 ton miles was required on the River Division, 160 pounds of coal per 1000 ton miles was required on the Eastern Division. Similar tests with an engine of practically the same tractive power, were made on the Ozark Division, between Harvard and Thayer. This portion of the Ozark Division may be considered as a line of average curves and grades for this section of the country, so far as Frisco Lines are concerned. The coal burned per 1000 ton miles on these tests averaged 101 pounds, or about 25 per cent more than was used in the test on the River Division. In the test on the Eastern Division only 80 per cent of the engine rating was handled, which makes the consumption appear higher than it would if the full rating had been handled as in the other two cases. On account of variations in loading and other conditions the results of such tests must necessarily be inaccurate, but show plainly that a very large increase in fuel consumption is caused by grades. To make the tests valuable for the purposes desired in this discussion, the same engine should be usdd in making the tests, and in this way it is believed a more satisfactory figure could be derived for the average proportion of coal used which should be charged directly to the hauling of the train, and exclusive of that portion due to the grade and curve resistance. The writer in comparing the theoretical performance of ~~two~~ an engine on two lines, has ordinarily figured the rise and fall, the curve resistance in terms of feet rise and fall, the total work performed in moving a ton the given distance at the average time card speed, or the average speed as taken from the engine performance sheets, and the work performed in raising a ton through the total number of feet rise. The coal performance is taken from the records of the fuel department, 25% to 30% is deducted for fuel not used in running, and the balance is divided according to the total work to be performed, in order to arrive at the per cent chargeable to distance, and to one foot rise and fall.

It mus-t be remembered, however, that in attempting to derive a value for the distance which will be lost or gained in grade reductions, it is not to be assumed that a level ~~grade~~ grade line will be reached, and that only that portion of the cost of fuel which is confined to the dierct hauling of the train on level track is to be considered. But rather do we wish to determine the increase or decrease to the present cost of operation if the distance be increased or decreased.

The per cent of the total coal used in actually hauling the train is evidently dependent in a large degree on the length of the division, the grades and the curves, and a number of other variables. Division accounts will probably give no information of value in dedermining the ratio for that division, as the complete information needed is not kept. The evidence recorded would indicate that as high as 80 per cent and as low as 60 per cent of the total fuel used would be increased or decreased directly with the distance. For the purposes of this report 50 per cent will be considered as varying directly with the distance, not because it is believed 60 per cent or 80 per cent is incorrect, but because conservatism is desired, and there are variations in the length of divisions and in operating conditions which might make a figure of over 50 per cent too high in certain cases.

Then in increasing the distance by the first two classes 50 per cent would be added to the fuel item and if we adopt 15 per cent as the average consumption due to stopping and starting, for increases of distance by the third class 65 per cent would be added to the fuel item.

The same division will be made for passenger service, but it is hoped further figures will be available in the near futube to shed more light on this important question.

As the cost of operation of fuel stations will depend within close limits on the amount of fuel consumed-we may consider the item affected in the same degree.

83.-Water for Road Locomotives:-The amount of water used will follow very closely the fuel consumption. There may be cases, where the increase in distance is several miles, where it will be necessary to erect additional water stations even though the number of station grounds is not increased. In such a case an additional stop for water would be necessary and of course the water bill would be increased on account of operating the additional supply station. It is probable, however, that such an increase would not increase the operating expenses per train mile. For the first two classes of increased distance, we will then figure 50 per cent affected and for the third class 65 per cent.

84.-Lubricants-Road Locomotives:-Theoretically, the amount of lubricants used should be in direct ratio to the distance. Actually this will not be the case. On a fast passenger run, for example, the engineer oils up only at regular stops, which may be twenty or thirty miles apart. On local trains it is customary to oil up about every third or fourth station, while taking water or where there is considerable station work. As far as cylinder oil is concerned this is not true, as the time occupied in the run is the controlling factoras regards ~~to~~ total amount used. Both of these facts however, show that the amount of oil used is not entirely dependent on the distance. We might reasonably assume that short increases in distance, not requiring any additional stops would affect the amount of oil used thirty per cent, this being about the per cent applied while running. Large increases involving stops will probably increase the item 80 per cent, account of lubricator being allowed to run, additional oiling up, etc. During short stops the lubricator will feed perhaps as much oil as is used running to the next station.

TRAIN SERVICE-

88.-Road Trainmen:-The pay of passenger conductors and brakemen is a fixed amount per calendar month, with limited mileage. Overtime is allowed on basis of fifteen miles per hour, computed for each part of the run separately.

Freight trainmen are paid on the same basis as the engineer's and fireman's schedule, viz:-the 100 mile basis, or the mileage basis.

In making up the passenger trainmen's schedule the mileage is considered to a certain extent, but it is not the determining facter. For example - the conductor's rate is $165.00 per month between Kansas City and Springfield for a 5,100-mile run. The rate is the same for the Monett-Paris run on the Central Division, for the Fayetteville-Okmulgee run on the Central Division, Springfield to Memphis run on the Ozark Division and so on, all for a 6,000 mile run. Minor changes in the length of line will thus probably make no difference in the passenger conductor's pay check, where no overtime is involved. The minimum time on run isten hours, that is, it is so considered in the pay schedule. After ten hours on a run which is ordinarily or scheduled less than ten hours, overtime is paid for over ten hours on the basis of 15 miles per hour, figured to the nearest hour. The same is true in case of longer runs, the overtime being figured only after the time card schedule has elapsed. As long as the time element is not increased no change in distance will affect the passenger trainmen's pay.

Increasing the distance by several miles may eventually cause a new schedule to be demanded, but this is of course speculative. Increase approaching the length of a division will probably require new schedules immediately, but for changes amounting to a few miles, and even those involving construction of new or additional station, we may consider the passenger trainmen's wages unaffected. The speed of trains in all probability will be increased enough to cover the increased distance without increasing the time on the road.

The increase in freight trainmen's pay will be the same for increased distance as was discussed under road enginemen, the first class of distance not being affected and the last two classes being increased 100 per cent.

CASUALTIES:-In consideration of the cost of running additional train it was arbitrarily assumed that 50 per cent of this general account would be increased by additional train. A study of the different items under this account shows that while they are all speculative expenditures, there is a close relation between their total and the train mileage. If the relation between casualties occuring at stations and between stations could be determined, an accurate basis for determining the effects of increased distance by the three classes selected could be determined. If we assume the two to be about equally divided the first two classes of increase in distance would be affected 50 per cent and the third class 100 per cent.

Of the remaining items of operating expenses a few will be affected in very small amounts, for the most part inappreciable unless changes in distance are great, involving the length of a division or thereabouts. On a railroad of 6000 miles or more the general expenses will not be appreciably affected by adding a few more miles. Doubtless a little more stationery will be used account of an additional station, the insurance premiums will be slightly greater, and in special cases more will be spent for signal men, crossing men, etc. The increase however, for distances under consideration, is for all practical purposes negligible.

Taxes is the only remaining item which will be increased to any extent. Taxes are intended to be levied according to the physical value of the property. As the tax levy is very different in different states, all that can be assumed is an average. It has already been determined that the side tracks at small stations constitute about nine per cent of the total mileage, and the side track mileage at large terminals about the same per cent.

Roughly, we may figure that a mile of track at small stations, together with its proportionate amount of the cost of buildings, right of way, etc., is worth twice as much as a mile of track between stations. A mile of track at terminals figured on the same basis is worth about four times as much as a mile of track between stations. On carrying out these figures and applying them to the total mileage statement, it may be shown that if the distance be increased by the first two classes the taxes will be increased five per cent, and if increased by the third class the taxes will be increased about 16 per cent.

SUMMARY AND CONCLUSIONS.

A summary of the figures derived shows that for freight service increasing the distance by class one, increases 18.09 per cent of the operating expenses, increasing by class two increases 29.31 per cent of the operating expenses, and increasing by third class increases 38.24 per cent of the operating expenses. It has previously been found that freight service constitutes 69.23 per cent of total operating expenses. Then increasing the distance by the three classes, increases the freight service cost 26.13 per cent for class one increase, 42.20 per cent for class two increase, and 55.23 per cent for class three increase.

The average cost per freight train mile was found to be \$1.58. Increase by class one distance would cost 26.13 per cent of \$1.58 or \$0.4128 per additional mile, or \$0.0000777 per additional foot, it being remembered that class one distance could only be applied where the pay mileage was not increased. On the basis of a daily train one way per year, the additional cost per foot of distance would be 365 x \$0.0000777 or \$0.028.

Increase by class two distance would cost 42.20 per cent of \$1.58 or \$0.6668 per additional mile, which for daily train one way for one year would cost 365 x \$0.6668 or \$243.37.

Increase by class three distance would cost 55.23 per cent of \$1.58 or \$0.8726 per additional mile, which for a daily train one way for one year would cost 365 x \$0.8726 or \$318.50.

The cost per annum of increasing the freight train distance might then be summarized as follows, for each daily train;-

Class one - per additional foot of distance	$ 0.028
Class two - per additional mile of distance	$ 243.37
Class three-per additional mile of distance	$ 318.50

Following out the same ,line of reasoning, we maydetermine the cost per additional foot and mile of distance in its relation to passenger service.

For passenger service it was found that increasing the distance by class one increases 8.68 per cent of operating expenses or 28.21 per cent of the cost of passenger service. Class two increase in distance increases 12.07 per cent of operating expenses or 39.22 per cent of the cost of passenger service. Class three increase in distance was found to increase 14.89 per cent of operating expense or 48.40 per cent of cost of passenger service. Carrying out these figures as was done for freight service the cost per annum of increasing the passenger train distance may be summarized as follows:-

Class one - per additional foot of distance	$ 0.018
Class two - per additional mile of distance	$ 117.89
Class three- per additional mile of distance	$ 159.00

The figures indicating the increase in cost will as stated in the first part of the discussion also indicate the value of any saving in distance which may be aacomplished in change of line or grade reduction. In order to determine the amount of capital which it will be justifiable to spend to decrease the distance according to any of the classes given, we should capitalizw the different classes. Below is given a table in which the different classes are capitalized, on the basis of 5% interest.

CAPITALIZED VALUE OF DECREASING THE DISTANCE ACCORDING TO THE CLASS INDICATED, AND FOR ONE DAILY TRAIN FOR PERIOD OF ONE YEAR.

Freight Service.

Class 1 - Capitalized value of one foot distance----$ 0.56
Class 2 - Capitalized value of one mile distance----$4867.40
Class 3 - Capitalized value of one mile distance----$6370.00

Passenger Service.

Class 1 - Capitalized value of one foot distance --$ 0.36
Class 2 - Capitalized value of one mile distance --$2357.80
Class 3 - Capitalized value of one mile distance --$3180.00

A practical application of these figures may be made in a change of line which is being made at the time this report is being written. On the Eastern Division of the Frisco at mile 131.5 between St. Louis and Springfield a revision of line is being made in order to eliminate 88 degrees of ten degree curvature, which has been the cause of several expensive derailments. Incidental to the elimination of this curvature, the line is shortened 60 feet. The cost of the work is estimated at $9500, of which $1100 is a charge to capital account and the balance a charge to operating expenses.

Assuming the cost of operation to be the average figures we have derived, the value of decreasing the distance, apart from the other considerations, may be estimated from the summary above given. There are eleven regularly scheduled freight trains daily over this track, together with an average of three "extras" daily, making a freight movement of 14 trains daily. The regular passenger movement is fourteen scheduled trains daily. Sixty feet of freight distance, for distance of the first class, under which this decrease would fall, would represent a sum of 14 x 60 x $0.56 = $442.40. Similarly the saving in cost of operating the 14 passenger trains would capitalize at 14 x 60 x $0.36 = $302.40. The total saving the, represented merely by decreasing the distance would be $744.88 or that amount of money could be justifiably spent for no other reason than decreasing the distance 60 feet. With this sole end in view the change being made would of course not be justifiable, as the total expense as stated is estimated at about $9500. Later in the report the value of eliminating the 88 degrees of curvature will be determined and it will be shown that a saving in operating expenses outside the saving due to accidents, should be made in this change of line.

Another example might be assumed to show application of the figures, considering the length of line on "Dixon Hill" from the Gasconade River to Dixon, between St. Louis and Springfield on the Eastern Division. The total distance by present line from the first curve west of the Gasconade River to the first curve west of Dixon is 61,000 feet. On an "air line" the distance between these two points would be 44,750 feet approximately. Or if the road had been constructed on a straig't line instead of in its c present location, about three miles of distance would have been saved. This distance would fall under class two. With the present train service the amount of money which could have been justifiably spent to have shortened the line this three miles would be expressed as follows:-

Freight service	3 x \$4867.40 x 14	=	\$ 204,430.80
Passenger "	3 x \$2357.80 x 14	=	99,027.60
	Total -------------	=	\$ 303,458.60

The total length of existing line is about 11 miles, and the "air line" would be about 8 miles. If we figure the original line cost \$40,000 per mile, \$120,000 could have been applied on the eight mile line without any resulting increase in total construction expenses, together with \$303,458.40, representing the saving in operating expenses capitalized. In other words, the amount it would have been justifiable to have spent for the eight mile line is \$783,458.40, or approximately \$98,000 per mile. The limited train service of the time the road was built of course did not justify such an expense, as the line would probably have cost all of the \$98,000 per mile. It is apparent from the figures that a large sum could be justifiably spent today to decrease the distance alone on this piece of track.

RISE AND FALL.

By the term ruling grade is meant the grade which limits the amount of tonnage which one engine may haul over a division at the assumed minimum speed. If a division was entirely level the ruling grade would be a level grade, or is the entire division was a continuous one per cent grade, the ruling grade would be one per cent. Such conditions seldom exist, however, and we find instead that the division is composed of numerous grades of different rates, a number of which may be considered as ruling grades, but which to be so considered must be of the same rate of grade. However, the ruling grade is not necessarily the maximum grade on the division, nor is it necessarily the longest grade. The reason for this is apparent after considering the laws of momentum or velocity, from which it is apparent that a train may acquire sufficient initial velocity to carry it over a grade greater in per cent than the maximum grade, but with a smaller total rise.

Some modification in the definition of the term ruling grade should perhaps be made on account of the fact that the resistance due to curvature may in effect increase the rate of grade enough to make an otherwise minor grade the ruling grade. From which it follows, that in speaking of the rate of ruling grade, it should be understood as meaning the actual rate of grade, plus the calculated increase by reason of the curvature. If the rate of the ruling grade is reduced on the curves, or as commonly stated, compensated, the ruling grade will actually be expressed as the rate of grade on the tangent.

The ruling grade may of course be found in a great many places on one engine district. But in case the ruling grade is found only once on a division or engine district, investigation should be made to determine if it may not be cheaper to operate it as a pusher or helper grade, rather than reduce the train load on the entire division. Whether this will be profitable will depend upon the increase in train load which may be made thereby. Each case of the kind will have to be figured on its own merits and will depend on the length of the grade, the number of trains, and upon the length of the division. If the division is less than 100 miles, there may be cases where the hill may be doubled without increasing the trainmen's and enginemen's wages, in which case the doubling would be more economical than the pusher service.

Outside of the ruling grade on the division, there are usually numerous lighter or shorter grades, none of which limit the tonnage to the extent of the ruling grade, yet some of which require almost the full powers of the engine, and perhaps would become the ruling grade if the otherwise ruling garde should be reduced. There are also lighter grades which are operated entirely by momentum, and on which the throttle of the engine is never changed. The only effect of such grades is a variation in the speed which has practically no effect on the cost of the transportation. The energy stored up in the descent of such grades is consumed in the following ascent and the fuel bill remains pratically the same.

As these lighter grades approach the ruling grade, however, a perceptible increase in the cost of operation occurs. The undulation of the grade line or the rise and fall becomes great enough so that steam is shut off during the descent to prevent too great velocity. This requires more steam to be used on the following ascent, as the potential energy which would be stored up for the ascent is lost in overcoming the frictional and other resistances on the descent, with the steam shut off. In case the drop is great enough so that brakes are required to prevent too great velocity of the train, we have still another class of rise and fall. These different classes evidently merge into and out of each other on certain rates of grade, and may make it difficult to determine in which class the particular grade belongs. By the help of the virtual profile, hereafter explained, there may be determined with sufficient accuracy the class for any particular train being considered.

We may divide rise and fall into three classes, then-

First:-Small undulations in grade, not affecting the amount of steam used.

Second:-Grades which require the partial or total shutting off of steam in the descent, but which require the full power of the engine in the ascent.

Third:-Grades which require shutting off steam and use of brakes in the descent, and full power of the engines in the ascent.

The question may perhaps be more simply stated if we assume first the case of a train running on straight level track. As already seen the resistance to be overcome in order that the train may move with uniform velocity are the rolling and journal friction, oscillation and concussion and air resistance. To overcome these resistances a certain number of foot pounds of energy must be transformed into work, and the resulting work is equivalent to raising the train a given distance. If we add to the resistances to be overcome, the resistance due to grade, the energy to be expended in drawing the train will be increased, as the other resistances will remain the same, if the speed be not increased. The first resistances increase with speed, however, while the grade resistance remains the same for all speeds. If in drawing the train the locomotive can make the required average time on the rise and fall without changing the amount of enrgy expended, there will be no change in the cost of the work. If, howover, more energy is required, the cost of the work will evidently be increased. In the second class of rise and fall it is evident more energy will be required, because the locomotive is an imperfect machine, and is producing energy in the shape of steam, whether it is used or not. While descending the grade with throttle closed or partly closed, the radiation still continues, and is a direct loss, and if the boiler pressure is being maintained the amount of steam which would ordinarily go toward drawing the train will escape through the pop valve and be lost. Under ordinary operating conditions, the steam will not begin escaping through the pop valve for some little time as a rule, for the boiler pressure will probably be lower than that for which the pop valve is set, owing to the fall in pressure which usually occurs when taking a "run at the hill" just surmounted, or in drawing the train for some time on level track, without a chance for any accumulation of steam. This in turn is caused by the necessity of keeping the injector running almost constantly with the result that the capacity of the fire box is taxed to produce heat enough to vaporize the constant stream of cold water entering the boiler. This is especially true in winter, when the feed water must ordinarily be raised thirty ot forty degrees more than in summer. The radiation is also greater in winter as the surrounding atmosphere is at such a reduced temperature. If the locomotive were a perfect machine producing energy only when needed, there would be no expenditure of energy from the engine while the train was descending the grade, and the total energy expended from the time the train started up the grade until it descended on the other side and regained the original level, would be the same as if the train had proceeded on level track. The increased cost due to the grade will then be represented by the internal losses in the engine, that is the loss of energy due to the method of operation of the train.

In another part of this report it is stated that on the Frisco the average weight of cars in freight trains is about 35 tons per car, and if we consider the average velocity as fifteen miles per hour, the resistance on level track would be 5.6 pounds per ton. This as seen later is the resistance due to a .28% grade, or a grade of 14.8 feet per mile. However, as the grades we are considering are to be operated to a certain extent by mementum it may be assumed the velocity at the foot of the grade will be the maximum safe speed or about 30 miles per hour. The resistance of a 3 5-ton car at a speed of thirty miles per hour is 7.3 pounds per ton, equal to the resistance on a .36% grade, or a grade of 19 feet to the mile. If this car reached the summit of a .36% grade running at thirty miles per hour and there were no accelerating or retarding forces acting upon it, other than the force of gravity, it would continue down the .36% grade at thirty miles per hour, as the total resistance in the car and the accelerating force of the grade would be equal. Any grade below this would be a retarding grade for a speed of thirty miles per hour, and some additional accelerating force would be required to maintain such a speed, thus bringing the rise and fall into the first class. Any grade greater than the .36% grade would be an accelerating grade and brakes would be required to keep the speed within the safe limit.

Practically, where rise and fall is continuous, a freight train will probably be loaded so that a speed of thirty miles per hour at the top of the grade in either direction will not be possible, and until that speed has been acquired on the descending grade no change will be made in the position of the throttle. In the discussion of velocity grades and acceleration, there is given a method for determining how far a train will run on such a grade or on any grade before such speed is acquired. The portion of the grade above such point may then be assumed as the first class of rise and fall, and the portion below as the second class of rise and fall, or if the grade is greater than the .36% grade it may be separated into all three classes. All of which shows that the length of the grade is a determining factor in deciding the class to which it may belong. As passenger trains are permitted to run at much higher speed than freight trains, it may be found that what would be considered the second class of rise and fall for a certain class of freight service will be practically a rise and fall of the first class for passenger service, or a third class rise and fall may become a second class rise and fall for passenger service.

The value of a foot rise and fall may be derived in a manner similar to that used in determining the value of curvature, given later. If the tractive resistance be doubled at the permissible safe speed on a grade of 19 feet to the mile, and we can determine what items of operating expense may be increased thereby, we may derive the value of 19 feet rise and fall, from which the value of one foot rise and fall may be found. It should be plainly understood however, that the results will be only approximate, as we may expect, as the value of the 19 feet rise and fall is based on resistances at assumed speeds which in practice vary within large limits. Average conditions are assumed as nearly as possible in order that the error may be as small as possible for resistances at other speeds.

Some writers have divided the cost further into the value of a foot rise and fall on minor and on ruling grades. Exception is taken to this, however, because the ruling grade is not necessarily the maximum grade and it is even probable that the wear and tear on the equipment due to a number of small undulations in grade will be greater than if the same grades were all combined into one ruling grade. It is true that the rail wear will probably be slightly greater on the ruling grade, due to the greater use of sand, but this will be more than offset by the effects of higher average speed on the minor grades. The point especially to be considered is the statement that wear and tear on equipment is greater on the ruling grade. This certainly appears to be an unjustifiable statement, and no evidence is furnished to substantiate it. On the ruling grade, while the draw bar pull is probably near the maximum, but not always necessarily so, is steady, while on the undulating grades it is exceedingly variable, so that if an equal amount of rise and fall composed of undulating grades is compared to a like amount of rise and fall on a ruling grade, there is every reason to believe the effects of the variable pull would cause a greater increase in operating expenses than the effect of a long uniform pull. The same is true of the down grade where the brakes are used. The greatest strain on the brakes comes with the first application, and if this is repeated a number of times it will probably produce more wear and tear on the brakes and on the equipment as well, than if the application were a continuous one.

In the table which follows no attempt has been made to separate the value of the rise and fall as affecting freight and passenger service. The reason for this is on the assumption that the resistance of passenger cars is the same per ton of weight as it is for freight cars, and thatthe average weight of passenger cars is about the same as the average weight of freight cars. While this is not entirely true, the latest experiments have shown that the difference at ordinary speeds is very small.

Following the table is a discussion of the reasons for selecting the figures indicated.

The Effect on Operating Expenses of 19 Feet Rise and Fall Per Mile.

Items Affected.	Percent of Whole	Percent Affected: Class 2	Percent Affected: Class 3	Percent Cost: Class 2	Percent Cost: Class 3
Locomotives-Repairs	10.05	1	4	0.10	0.40
Passenger Cars-Repairs, ets.	1.54	1	4	0.02	0.06
Freight Cars-Repairs	0.70	1	4	0.07	0.266
Shop Mach. & Tools	.53	1	4	0.01	0.02
Fuel for Road Loco.	9.80	40	45	3.92	4.41
Water for Road Loc.	.70	40	45	0.28	0.33
All other items of Expense----	70.00	00	00	00	00
Total----------	100.00			4.40	5.48

In general it may be said that the adoption of velocity grades requires that the track be kept in more perfect line and surface than would be necessary if there were no grades. The reason better maintenance is required is because of the high speed. If the division was level, the speed could be maintained at a given rate and with very little fluctuation. Practically, however, in maintaining track, we seldom find any difference in the amount of money appropriated to maintain different sections of the same division. The section with the grades of course suffers, and the result is that the section foreman spends most of his time on the high speed part of his section and only enough time on the remainder to enable trains to "get over." His work is made somewhat easier by reason of the better drainage of the track as the cuts drain well, and the track holds its surface better than the level track in cuts. On ruling grades where heavy curvature exists, the section forces are somewhat increased, or the length of these sections is reduced, but in considering the cost of rise and fall, while it is probably correct theoretically to say the track maintenance is increased, we cannot actually say it is, and must neglect such increase. The same thing may be said of renewals of ties and rails. While there is probably a slightly greater wear on track material due to fluctuations in speed and to the use of sand, this is practically negligible and we do not find that rail is replaced any sooner on the grades than on the level track, unless it be because of wear due to curvature. The rail when released will probably go into side track and possibly into branch lines, and will last just as long as long as the rail from level track. In the second class of rise and fall where no brakes are used, this should be literally true, as there is no reason for saying the rail wear would be increased unless the wheels were slipped.

This may occur on the engine occasionally, requiring some sand, but is undoubtedly a negligible quantity. For the third class the rail wear may be increased by a partial sliding of the wheels with the brakes set. Some experiments carried on by the Pennsylvania showed that with heavy braking power the cars traversed a greater distance than the number of revolutions of the wheel indicated, showing that sliding actually occurred. This is often observed when a train is coming to a atop with the brakes fully set, and there is every reason to believe it occurs unobserved whenever the brakes are applied. The custom of braking only to about 70 per cent is brought about in an attempt to eliminate such sliding and yet obtain sufficient braking power to get the maximum efficiency out of the brakes without sliding the wheels. If the life of a rail could be followed from the time it is rolled until it becomes scrap, it would no doubt be found that those rails which had been laid and used at heavy braking points would find the scrap pile first. We have on this railroad today, however, in class "B" track, some 40# rail laid nearly thirty years ago, and on a one per cent grade entering a station, and yet this rail is apparently as good as the day it was laid, except for the rusting which has naturally occurred. The size of the ball is practically the same as when the rail was rolled. The trains on this track are such that the locomotive need not be over-rated, which may in some measure be responsible for the fact that this rail is still in the track. Over-rating may occur on level track as well as on grades, howvere, and losses due to such a practice should not be charged to the results of such a practice. These and other reasons which might be enumerated, make it seem wise to not consider any increase to maintenance of track due to these different classes of rise and fall, After studying over each item of operating expense very carefully, there appears to be only two general accounts which are in any way appreciably affected. They are the fuel and water bills and the equipment repair bills. The first include fuel and water for road locomotives and the second repairs to locomotives and cars, and maintenance of shop and tools which is necessitated thereby.

25:-Steam Locomotives-Repairs:-The calculated cost of rise and fall it will be remembered is upon the basis that the resistance per mile is twice that on level track, or twice ordinary train resistance consisting of journal and air resistances and the resistances due to oscillation and concussion. It does not necessarily follow that by doubling the resistance the cost of operation will be also doubled in so far as the cost of engine repairs is concerned, any more than that running twice the distance will double the cost of repairs. And in fact there is no accurate way of determining what the additional cost of repairs will be. We know that the greatest contributing causes are the unequal strains caused by changes in tractive resistance behind the engine, and renewals of wheels and brake shoes. When running on level track the draw bar pull should be uniform at uniform speed, and in fact is very nearly uniform. By referring to dynamometer charts, however, it will be seen that at the instant the slack is pulled out of a train in a sag the momentary draw bar pull is several times greater than it will be when the train is stretched out again and each car running at the same speed. The locomotive is thus subjected to additional strains and stresses due to the varying load or speed on the grades. In addition to this the running gear is subjected to much greater wear and tear while running with steam shut off, due to loose bearings, and the cylinder and rings wear faster because of less lubrication. It is quite evident that the effects of all these forces will differ in different makes of engines, and in the same engine under different handling and varying conditions, and it has so far been found impossible to accurately assign the various items of repairs to their contributing causes. Records of locomotive repairs kept on mountain divisions show a surprisingly small increase in the cost per car mile over repairs on comparatively level divisions. Of course this is partly accounted for by the fact that the tonnage per engine mile is small compared to the valley routes.

A comparison for several years of the cost of locomotive repairs on the Chicago and Eastern Illinois R. R.

and on the Frisco Lines proper, shows that the cost of repairs is about $0.004 per train mile greater on the Frisco than on the C. & E. I., which may be considered as a level railroad compared to the greater part of the Frisco. The class of power is very nearly the same on the two roads, which shoud give some indication of the increased cost of operating the grades on the Frisco. As has been stated, the only additional cost that may be charged to rise and fall will be that caused by g grades which cannot be operated without changing the engine throttle. As the loading varies, so will the grades affected vary. If an engine is pulling its theoretical loading at all times, the grades which might be classed as affecting the cost of operation could be ascertained but this cannot be done, as some trains will run past stations at one time, and stop another, or engines may be overloaded or underloaded, thus changing entirely the virtual grades line. On an assumed virtual grade line based on a theoretical rating, or better on the average per cent of time card rating actually handled, we may determine the grades which will be classed as affecting the cost, although in practice such grades may not always be operated in such a manner.

If we assume that $0.004 per train mile is fairly representative of the cost for the 19 feet per mile, and which would evidently be for the combined class two and three rise and fall, and that the total cost of repairs is $0.10 per train mile, the increased cost for class three would not exceed four per cent of the average cost of repairs. The average rise and fall on the Frisco exclusive of difference of elevation of terminals, is 14 feet per mile, based on the performance of our average freight engines, taken as engines 741 to 727, and handling their theoretical rating. We may consider from study of the profiles that about one third of this rise and fall is operated as the first class, or that about 10 feet per mile is operated as the second and third class. Roughly, then 10 feet rise and fall per mile should increase the average cost of repairs about 8 per cent. We may further assume that about one-half of the rise and fall is operated by momentum, due to the actual loading on the engines and the speed attained by reason of light tonnage, or that about four per cent will actually represent the increased cost. This is the figure ordinarily accepted in estimating the cost, although unfortunately none of the authorities have stated how they arrived at such a result. It is admitted that the manner of arriving at the result given is at the best only very approximate, but it gives some fairly good basis for determining the value sought. Of the total we may assume 75 per cent is chargeable to renewals of wheels and tires and of brake rigging, and the other 25 per cent to draft gear, this being approximately the average relation between the cost of these two items. On the basis derived, the increased cost for the second class of rise and fall will be one per cent, and for the third class four per cent, as in the fourth class the first class is also included.

Even if two engines, both new and exactly alike, were placed in service, one on a level track and the other on a hilly division, and run for years, it would be found that there would be no accurate method of determining the cost of repairs as caused by the grades. This in effect has been attempted, but the results failed to give the deisred information. This is partly due to the difficulty of keeping accurate records, and to the personal equation of the men handling the engines and making the repairs. It is also difficult to compare the results due to the great difference in tonnage handled, a division of much rise and fall usually being a division of heavy grades as well, making the tonnage handled per engine mile much less than on the level division. No other proof than what we have is necessary to show that the cost is increased by this rise and fall, and comparison of the cost of repairs on roads of light and heavy grades probably furnishes as good evidence as may be obtained.

Passenger and Freight Car Repairs:---As the contributing causes of car repairs are the same as the contributing causes of locomotive repairs, it may be assumed that the repairs will be affected in practically the same per cent. As a matter of fact, the forces acting, will be less in magnitude, depending on the length of the train, and the effect or the cost of repairs greater in proportion, as the material in a car will not stand the same amount of strains that an engine will. In the end, however, the per cent affected is probably very little different, and we will consider it as the same.

Shop Machinery and Tools:---The magnitude of this account each year will depend upon the amount of repair work done, and any increase in repairs to locomotives or equipment will make a corresponding increase in repairs to shop machinery. The total additional cost of operation due to repairs will amount to \$0.0097 for 19 feet of class three rise and fall per mile, and \$0.00024 for class two. The cost of one foot capitalized at 5% interest would be \$0.01 for class three and \$0.0025 for class two. In other words, if the estimated additional cost of repairs was in error 100 per cent the money which it would be justifiable to spend would still be insignificant as compared to the cost of the work. Hence it is evident rise and fall so far as considered is a minor saving. We have yet to consider the additional cost of the fuel and water.

<u>Fuel for Road Locomotives:</u>--This account includes 9.80 per cent of all operating expenses.

As stated above, if the locomotive was a theoretically perfect machine, developing power only as needed, there would be no incresed cost due to the 19 feet rise and fall, if all the work was done in half the distance. In climbing the grade the coal consumption will evidently be the maximum until the summit is reached. At that point no further steam is needed for the descent, but the fire must be kept at the maximum for the following ascent, and the energy is wasted in the shape of steam blown off thru the pop valve, or in the third class it is used partly to retard the motion of the train and is dispelled in the form of heat from the action of the brakes. If the rise and fall should occur in short stretches, demanding the maximum coal consumption at all times, the increased cost would be practically one hundred per cent. This seldom occurs, however, and if we consider that at the end of the mile the boiler needs only supply enough energy to draw the train on the level track the increased fuel consumption will become something less than fifty per cent. Experiments have been made in view of making an accurate determination ofthis, but with greatly varying results, passenger engines showing different results from freight engines, etc., owing to the different form of firebox construction and the different amount of coal consumed in maintaining boiler pressure. No known experiments have been madeon this railroad, hence we are required to accept figures derived by other roads. These vary from 30 to 50 per cent increase by reason of doubling the tractive resistance. Assuming twenty per cent of the total fuel consumed is used for firing up, in standing and for other things than actually drawing the train, and calculating the theoretical work done in doubling the tractive resistance over a mile of track, we could derive a figure of approximately 40 per cent as the increase due to the rise an fall. If we consider that the train is split in two sections at the foot of the grade and hauled with two engines, thereby cutting the tractive resistance in two, or making the total for each train the same as for the full train on level track, and that the extra engine was done away with at the top of the hill, we might say that the extra fuel used would be half that for the additional train or 37 1/2 per cent.

In making actual experiments one other feature would have to be considered. Two kinds of coal which cost the same in the tender may have greatly different heat units, and the cost of supplying the additional energy may be much in excess for one fuel compared to another. The relative increase in cost would under such circumstances of course vary. For estimating purposes, however, we will assume that the account is increased forty per cent for the second class and forty-five per cent for the third class, adding five per cent to third class due to energy wasted in aplication of the brakes.

The water bill will be increased in practically the same proportion as the fuel bill. Actually the increase may be somewhat greater due to condensation in the cylinders after allowing them to cool off somewhat on the down grade, and to the longer cut-off on the up grade.

SUMMARY AND CONCLUSIONS.

A summary of the per cent additional cost for the two classes of rise and fall under consideration, shows that 19 feet of class two increases operating expenses 4.40% and class three 5.48%. The average cost per train mile as already determined was $1.29. The additional cost for 19 feet rise and fall of class two would then be 4.40% of $1.29 or $0.057 and for class three 5.48% of $1.29 or $0.071, or the additional cost per foot of class two rise and fall would be $0.0029 and for class three $0.0037 per foot. Capitalized at 5%, the justifiable expenditure to eliminate one foot of class two rise and fall would be $0.58 and for class three $0.74.

These figures are considerably less than the ordinary calculated values of a foot rise and fall of the two classes mentioned, but no justification can be found for any increase in the items affected.

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Helper Grades and Their Cost.

In laying out a railroad, it is frequently found that there is one or perhaps two places on a division where it is physically or economically impossible to adopt a grade which will be no greater than the ruling grade possible for the remainder of the division. This condition is especially true in mountainous country where it is often necessary to cross a divide. Rather than reduce the train load on the entire division, a grade heavier than the otherwise ruling grade is adopted and trains are helped over this grade by the use of an additional engine, or as many as are necessary to handle the traffic. These grades are known as helper or pusher grades. A helper grade may then be defined as a ruling grade, greater than the ruling grade on the remainder of the division, and which it is cheaper to operate by the use of helper engines, rather than reduce the train load on the entire division. Such grades are found on this railroad between Rolla and Dixon, and near Winslow and Talihina.

It is of course essential to know the cost of the helper service before adopting such a grade, as it may be found that the cost of the service will be greater than the cost of reducing the helper grade to the otherwise ruling grade. Often, however, it is physically impossible to do this, and the question then is, whether it is cheaper to operate the helper grade or reduce the tonnage per train mile. This question is easily decided in most cases, as reducing the tonnage per train increases the train mileage. We have found that handling a given tonnage in two trains instead of one increased the operating expenses about forty per cent. It is evident therefore that if the train mileage is doubled for only a small portion of the division the cost of operation will be increased less than if the train mileage is doubled on the entire division.

The economy of helper grades may be stated as established then in case where it is necessary to either adopt a helper grade or double the engine mileage. Obviously, the shorter the helper grade the more trains can be helped over it by one helper engine. For this reason, it is well to adopt the maximum grade on which two engines can pull the train at the assumed minimum speed, in order to derive the maximum efficiency from the helper. This may be illustrated by assuming a case. For example- the ruling grade on a division is one per cent, and the engines are loaded to maintain a speed of ten miles per hour on this ruling grade. A helper grade is found necessary at some point, which may be constructed with a minimum 1.4 per cent grade or with a ruling grade ranging anywhere between 1.4 per cent and 2.0 per cent. The use of the helper engine will about double the available tractive power on the helper grade, so that the most economical grade line will be the one where the tractive force required is about double the tractive force required on the ruling gradient. By figures given later in this report, this grade may be determined. The adoption of this most economical grade line will reduce the length of the helper grade to a minimum and thereby permit of more trains being helped with one helper engine, as the mileage of the helper engine per trip will be reduced to a minimum. From a construction standpoint it will, as we know, ordinarily be cheaper to build a two per cent line than a 1.4 per cent line, although due consideration should be given to the cost of the work in adopting the maximum economical grade line for the helper service. A high cost of construction may offset the saving due to the shorter line.

Granting that it is not possible physically to eliminate a helper grade, there is only one other consideration to be given that particular grade. If reduction of the otherwise ruling gradient is made on the division, can the helper grade be reduced to such a point that the train load possible on the remainder of the divisiion, may be handled on the helper grade without increasing the train mileage. For example, one helper engine might not be able to help the maximum train on the reduced ruling grade over the helper grade, in which case either larger helper engines, more helper engines, or reduction of the helper grade would be necessary. If the helper grade was built on a two per cent grade line where a 1.4 per cent grade line was possible, the necessary reduction might be made economically, but if the two per cent grade was built in a two per cent country it might be found more economical to double the hill or use two helper engines.

on the other hand, we may imagine a case where a helper grade has been constructed because it could be operated cheaper with the volume of traffic offered, or in other words, because the additional cost of operation was less than the interest on the investment necessary to reduce the grade to the otherwise ruling grade. This condition, presumably true when the road was constructed, may not be true today, and a study ofthe cost of operation may show that the interest on the money necessary to eliminate the helper grade may be much less than the cost of operation. Before we can say this is true, we must know as nearly as possible the cost of the helper engine service.

In determining the cost of running an additional train to handle a given traffic, it was found that the greater portion of the additional cost was due to the additional engine mileage. The same will be true to a large extent in estimating the cost of helper service, but the helper service will cost less because there are several items of operating expenses such as trainmen's wages, extra caboose, etc., which will not be charged to helper service. The items affected are all affected in the same per cent as in the case of running the additional train, so that in the table given below there is no discussion of the reason for selecting the various figures, as the reasons may be found in the previous discussion. The might be at first glance some reason for thinking the cost of fuel, oil and water should be greater than in the previous case. However, it must be remembered that the helper grade is such that with two engines working, the tractive effort should be no greater than on the ruling grade on the remainder of the division. On the return trip the engine drifts down the hill, and although this also happens with the road engine, the helper grade is only a smallportion of the road engine's run and many heavy pulls are necessary in the same direction as the down grade of the helper grade. Actual running tests on Dixon Hill show the cost per 1000 ton miles for coal on the helper engines is practucally the same as the cost per 1000 ton miles for road engines.

The table given below is separated to show the cost for freight and passenger service as in the case of running an additional train. The estimate is based on the assumption that the helper engine makes at least 100 miles per day, which will nearly always be the aase. If less than 100 miles is made, the cost per mile will be greater, but the total cost of operation will be the same.

Freight Service.
Cost Per Cent of Helper Engine Per Mile.

Items.	Percent of Whole	% Affected By Helper Engine.	%Cost for Helper Engine.
3.-Ties	3.21	12 1/2	.40
4.-Rails	.38	24	.09
5.-Other track material	.62	24	.15
6.-Roadway and Track			
(a)-Track maintence	2.40	24	.58
(b)-Appl. Trk. Matl	1.15	13.9	.16
16.-Bldgs, fixt & grnd			
(b).-Fuel & Wat. Sta	.22	10	.02
18.-Roadway Tools-Supp	.23	16	.04
25.-Steam Loc-Repairs	6.47	85.6	5.54
26.- " " Renewals	.01	85.6	.01
27.- " " Deprectn	.05	85.6	.04
46.-Shop Mach & Tools	.38	42	.16
80.-Road Enginemen	4.48	100	4.48
81.-Eng. Ho. Exp-Road	.85	100	.85
82.-Fuel for frt. Loco	6.64	75	4.98
82-c-Oper. Fuel Sta.	.19	75	.14
83.-Watre for Road Loc	.49	75	.37
84.-Lub. for Road Loco	.15	100	.15
85.-Other sup." "	.11	100	.11
Total--------			18.27

Passenger Service.

Items.	Percent of Whole	% Affected By Helper Engine.	%Cost for Helper Engine.
3.-Ties	1.23	12 1/2	.15
4.-Rails	.14	24	.03
5.-Other track material	.22	24	.05
6.-Roadway & Track--			
(a)-Appl. Track Matl	.43	13.9	.06
(b)-Track Maintenanc	.88	24	.21
16-b-Fuel & Wt. Statns	.14	10	.01
18-Roadway Tools & Sup	.10	16	.02
25.-Steam Loc-Repairs	3.48	85.6	2.98
26.- " " -Renewals	.01	85.6	.01
27.- " " -Deprectn	.03	85.6	.02
46.-Shop Mach & Tools	.15	42	.06
80.-a-Road Enginemen	2.36	100	2.36
81.-Eng. House Exp-Rd.	.55	100	.55
82.-Fuel-Passenger Loc	2.85	100	2.85
82-c-Oper. Fuel Stat.	.12	100	.12
83.-Water for Road Loc	.21	100	.21
84.-Lub. Road Locomot	.09	100	.09
85.-Other sup.Road Loc	.10	100	.10
Total----------			9.88

The totals show that the cost per cent of the helper engine for freight service is 18.27% per mile which is 27% of the cost of operation per freight train mile, or 26.4%

of \$1.58 which is \$.41 per mile. Carrying out the figures for passenger service the cost per mile is found to be 32.1 per cent of \$.90, or \$.29 per mile. In using these figures, it is very important that one thing be remembered, and that is the number of helper engines which will be used. If the fact that passenger trains need helper engines increases the number of helper engines, then the cost of the service should be figured from the number of freight trains assisted and the number of passenger trains assisted. But it will often happen that only the freight helpers are required, in which case the figures for freight service only should be used. It is for this reason that the two are separated.

The cost of helper service per daily freight train per year derived from these figures would be \$.41 x 365 or \$149.65, and the cost of helper service per daily passenger train per year would be \$.29 x 365 or \$106.85. However, for each train assisted up the grade there would be an engine returned light, so that we should really say that each mile of helper service for freight trains costs 2 x \$149.65 or \$299.30 per daily train per year, and for passenger trains 2 x \$106.85 or \$213.70 per daily train per year. This as before stated is on the basis of not less than 100 miles per day engine mileage per engine.

If all trains are assisted by helper engines we may neglect the separation between freight and passenger service and use the average cost figures. It was found that the total cost per cent of the service was 28.15 per cent of the average cost per train mile, or 28.15 per cent of $1.29, which would be practically $.36 per helper engine mile.

In order to substantiate the figures given as to the cost of helper service, there is given below a statement prepared by Mr. C. D. Purdon, while Consulting Engineer for this company, which gives the actual cost of the helper service between Rolla and Dixon for the year ending December 31, 1906. While some of the operating expenses have increased slightly since that date, the figures will give a very good check on the estimate already prepared. The statement follows:-

"Between Rolla and Dixon for the year ending December 31, 1906, the cost of helper service was as follows:-

Fuel,----------------	13,715 Tons	$ 25,458.49
Repair, labor--------		1,871.16
Repair, mat'l--------		971.45
Supplies-------------		77.91
Oil and waste--------		443.89
Water----------------		805.50
Sand-----------------		84.40
Inspecting engines--		81.00
Handling engines---		735.21
Wages - Rolla Dist--		3,479.06
Wages - Lebanon Dist		8,197.60
Total two engines day and night ------		$ 42,205.67
For one day and night helper --------		$ 21,102.83

"The cost cannot well be divided between Dixon Hill and Rolla Hill, as the coal, supplies, etc., are not kept separate, but taking the same percentage as the wages, we would have:-

	DIXON HILL	ROLLA HILL
Fuel,-----------	$ 17,871.85	$ 7,586.67
Repairs,--------	1,995.51	847.10
Supplies,-------	991.01	420.59
Inspection, etc-	572.98	243.23
Wages,----------	8,197.60	3,479.06
	$ 29,628.95	$ 12,576.72
Or for one engine------	$ 14,814.47	$ 6,288.36

"The cost of service on Iron Hill (Mosella) is given for seven months:-

Fuel,--------------	$ 2,174.98
Repairs,------------	506.18
Supplies,-----------	452.57
Inspection,etc.,---	71.58
Wages,-------------	2,223.31
Total seven months	$ 5,428.62

(For one year at the same rate the cost would be $9,306.20.)

"This does not include interest and depreciation on the engine which of course would be based on the cost of the engine."

"The engines used were --

2652 valued at $ 3,948.73 in 1903.
#2680 valued at $ 9,001.50 in 1890.

"The mechanical department calculates interest at 6% and depreciation at 5%. Taking the above, values would average $712.26 annually for each engine, making about $22,000.00 per year for one day and night helper. I had estimated $20,000.00."

If we take only the figure affecting Dixon Hill and add the $712.26 for interest and depreciation, the cost for one engine would be $15,526.75. The same basisi of figuring for Rolla Hill would show the cost to be $7,000.62 per engine, or about 45 per cent of the cost of the service on Dixon Hill. The round trip run on Rolla Hill is 17 miles and on Dixon Hill 31 miles, or the Rolla run is 55 per cent of the Dixon run. We would expect the Rolla run to cost a little more per engine, as the run is shorter and there would be a greater per cent of the time when the engine was not actually running. While these figures are four years older than the other figures which we are using, they should be fairly reliable and should indicate about what the service is costing today. There are at present five helper engines working between Rolla and Dixon. According to Mr. Purdon's figures, one day and night helper per year should cost $21,102.83 plus $1,424.32 interest and depreciation, pr $22,527.15, or the five engines should cost $56,317.90 per year. The average number of trains helped on Dixon Hill is about 12 per day and on Rolla Hill about four, so the daily helper engine mileage would average about 440 miles. The cost per helper engine mile for daily train on this basis would be $.35. Our previous figures indicated the average cost as $.36. These figures, however, included certain items of expense not considered by Mr. Purdon, such as increased wear on ties and rails, etc. If we consider only the items included in Mr. Purdon's estimate, it is found that compared to his figures, our estimate would be 26.02 per cent of $1.29 or $.34 per helper engine mile. The two figures being only $.01 apart seem to justify the method we have used in arriving at the cost of the helper engine service from the estimated increase in cost of operation.

In 1904 a complete survey and estimate was made to determine the cost of reducing Rolla and Dixon Hills to an .8 per cent compensated grade. The total length of the survey was 30 miles as it was necessary to join the old main line west of Dixon. The total estimated cost of the work was $1,802,649.59 after allowing for salvage on the line abandoned. If we capitalize the cost of the helper engine service today, we would be justified in spending only $1,126,358.00 for this work, so that considering only the saving in helper engine service, the work would not be justifiable as yet. As no saving is to be expected in the number of trains by such work, the only other saving was by reason of the decrease of 2.3 miles in total distance, and the saving of 2359 degrees of curvature. If we apply the figures derived for saving in distance and curvature it will be found that the cost of the work and the saving to be expected, just about balance each other. As the money can be used to better adavntage elsewhere there is no good reason for doing the work at present.

The cost of helper service has actually been found to vary greatly, and in using the figures presented here, it should be remembered they are based on the assumption that the full efficiency of the helper engine is obtained. Another important consideration will be whether the helper grade requires the maximum tractive power of the helper engine, efficiency as spoken of in the former sentence meaning principally efficiency in point of time in operation. In case the maximum tractive power of the helper engine is not being secured, it may be advisable to make short relocations, increasing the rate of helper grade in order to make a reduction of some otherwise ruling or heavy grade, as well as shorten the helper grade. It is evident the most economical conditions will be those where the number of trains is such that the maximum mileage of the helper engine is required, and also the maximum tractive effort.

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CURVATURE AND ITS EFFECT ON OPERATING EXPENSES.

In consideration of the value of decreasing curvature there are several factors to be considered, all of which are more or less uncertain when an attempt is made to reduce them to actual cost figures. In a general way the proposition may be stated in about the same manner the advantages or disadvantages of grade reduction as a whole has been considered, viz:- to be profitable to reduce the curvature, it mus t be shown that the saving in operating expenses to be effected thereby, must be greater than the interest on the money necessary to eliminate such curvature. The degree of curvature used affects in some degree the distance, hence should be given the proper consideration in determining the maximum curvature to be adopted. The longer the radius of the curve adopted the less will be the total distance between two points. For example, a ten degree curve at the apex of two long tangents would make the total distance greater than a two degree curve between the same tangents, because the two degree curve would fall on the inside of the ten degree curve. While in any one curve the difference in distance would probably be small, in a hundred mile division there would be a very appreciable lengthening of the line by using sharp curvature. To show this in a numerical example suppose ten tangents each a mile long connected with forty degrees of ten degree curves, then replace these nine ten degree curves with one degree curves. In the first case the total length of line would be 56,400 feet and in the second case the total length of line would be 55,016,feet, or a saving of 1,384 feet would be made by using the lighter curvature. On a hundred mile division of the same kind there would be two and a half miles of line saved which would be worthy of consideration to say the least. So that outside of other considerations there is some consideration to be given the amount of curvature as affecting the length of line.

In writing on the subject of curvature, Prof. Webb says in part;

"In the popular mind curvature is perhaps the most objectionable feature of railroad alignment. The popular mind readily perceives the curvature as a fact, when a grade which is more costly from an operating standpoint is not perceived at all."

Prf. Webb summarizes the objections to curvature as follows:-

"1.-Danger-The added danger of collision, derailment or other form of accident which is due to curvature."

"2.-Effect on Traffic-A road sometimes loses passenger traffic on account of the apprehension of danger or because the curvature produces rough and unpleasant riding, or because it reduces somewhat the speed of trains and therefore the time between termini-etc".

3.-"Effect on operating trains - Curvature has some limiting effect on the length of trains, and it is claimed that it limits the use of heavy engines."

4.-"Effect on operating expenses - Curvature increases these expenses by (a) the required tractive force; (b) wear and tear on road-bed and track; (c) the wear and tear on equipment; and (d) the required number of track walkers and watchmen."

Most engineers will agree that there is some added danger from collision, due to curvature, in the sense that collisions may be made more costly by reason of occuring on curves where trains may meet at high speed, where time perhaps for a full stop and avoidance of a collision would be had on straight track. This, however, cannot be directly charged to curvature as it is caused by defects in operation. Neither can it be said that the fact that a track is curved, is responsible to any large extent for derailments,for, experience has shown conclusively that on ordinary rates of curvature there has been an exceedingly few instances where curvature has in any way been responsible for the derailment. There is, however, one feature of derailments on curves which becomes directly an added cost in most derailments on curved track. That is the fact that in most instances the train is turned over, caused by its tendency to follow the tangent to the curve, thus causing the train to leave the fill or wreck itself on the sides of the cuts.

It may be true in cases of competing lines that some traffic will be deflected from the line of greater curvature, but this is probably more than offsetted by the tourist travel over the line with many curves, which is usually a picturesque route. For this reason it may be said that the net effect of curvature on passenger traffic will be inappreciable, and of course freight traffic will be entirely independent of such conditions, except in such cases where the curvature would very greatly reduce the time of freight over the road, a condition hard to conceive.

The effect on operation of trains and the effect on operating expenses should be studied together, as the latter is the direct effect of the former. And these two features of the subject are the ones the engineer is the most vitally interested in. It is not in his province to divert the passenger traffic to his line or to see that freight trains do not collide on curves, but it is his problem to say what the cost of operation over a line with great curvature will be as compared to cost of operation on a line of small curvature, and whether the cost of reducing the curvature is justifiable. As already stated in this paper it is not the locating engineer's view point of curvature with which we have to deal. He must assume his operating expenses from his knowledge of the particular kind of railroad he is building, while we have the actual cost of operation and the actual cost of the physical line as well. Thus what might be an economical line to build today with a known train movement, might not be an economical line if developed from an old line already having heavy interest charges. So that an exceptionally good location from the standpoint of a newly constructed line today, might be a losing proposition from a reconstruction standpoint and it becomes the engineer's duty to find the line which will present the most economical solution of the problem.

The question to be determined, then, is the value of eliminating any given amount of curvature. The method employed will be similar to that employed in determining the value of decreasing the distance.

In dealing with curvature we have several variables. For instance the rail wear on a curve will depend to a large extent on whether the speed of all trains is uniform on that curve or whether some trains run at a slower speed and some at a higher speed than that for which the curve is elevated. To illustrate:-On the Frisco the elevation of the outer rail is figured from the formula $E = \frac{V^2}{1/4R}$, or in other words the elevation varies as the square of the velocity. Obviously then, it will be impossible to elevate the outer rail properly for all speeds, or for all trains, and in case the speed of the trains is greater than that for which the track is elevated, the outer rail will be subjected to excessive wear by reason of the centrifugal force due to improper elevation.

If the elevation varies according to the square of the speed, it at once becomes evident that the effects of centrifugal force due to improper elevation, will vary as the square of the speed. The effect of curvature on operating expenses, them, will depend primarily on two things, viz--whether the trains run at the speed for which the track is elevated, thus determining largely the proportion of mechanical wear chargeable to curvature, and the percent of curvature as compared to tangent track.

The first question which presents itself in the numerical solution of the problem, is whether the effects of curvature depend on the length of the curve, or on the total angle of the curve. In other words, will the effect on operating expenses be the same for one thousand feet of a one degree curve as for one hundred feet of a ten degree curve. Wellington says that for all practical purposes such is the case. This conclusion has never been satisfactorily proven but is generally accepted, and if true we may state that the effect on operating expenses will be in proportion to the number of degrees of curvature, hence we should establish a value per degree of curvature and not per degree of curve. If we consider a 100 ton locomotive on a one degree curve one thousand feet long, or a distance X, and running at speed of twenty miles per hour, the total force due to curvature to be overcome in keeping the locomotive on the rails would be expressed by

$$f = X \frac{Wv^2}{Rg} = 436 X$$

If this same engine was considered on a ten degree curve one hundred feet long the formula would become

$$f = \frac{X}{10} \frac{Wv^2}{Rg} = \frac{4360 X}{10} = 436 X$$

or in other words the total work done would be the same. In the first case the rail wear, etc., would be spread through a large distance and would be small per unit of distance, and in the second case the wear would be theoretically greater proportioaately and the distance proportionately shoretr, leaving the total effect the same. If the effect on operating expenses is proportional to the centrifugal force to all practical purposes, as commonly accepted, our problem will be considerably simplified. The greatest objection to using such a hypothesis is the fact that these forces increase with the square of the velocity, and for this reason the effects of improper elevation, or improper speed for the elevation, imperfections in equipment, or unbalanced loads, etc., will be such that the greater in velocity the train speed, the greater in proportion as the square of the velocity will be the destructive effects on the roadbed and equipment. So that for a theoretically perfect condition of roadbed and equipment we would probably not be far astray in saying the effect per degree of curvature was the same, but with the actual conditions we would probably find that the length of the curve has some effect on the operating expenses, even though the total angle be the same. For example consider the track work necessary to resurface the 1000 feet of track after being knocked out of line due to improper elevation, as compared to the work necessary to resurface the 100 foot curve. In this case the distance is certainly the controlling factor as the cost of surfacing will be practically the same in either case per foot of track. To offset this, is the fact that the one degree curve is not as easily knocked out of line and surface, and does not require as many resurfacings as the heavier curve.

There has been certain phenomena discovered in connection with rail wear as affecting the total wear on inner and outer rails on the same curves, which shows that for curvature up to about four or five degrees the wear on the two rails is about equal, but that when ten degree curves are approached the excess wear occurs on the inner rail, due to the slipping of the wheels on the inner rail. In some cases it was found that this excess wear on the inner rail amounted to three times the wear on the outer rail. The portion of the ball abraded, however, is different, it being the side of the ball on the outer rail and the top of the ball on the inner rail. For this reason we have to remove the outer rail long before the inner rail, as the rail is weakened much more by the side wear on the ball than by the top wear. The average wear per degree of curvature has been found to be quite uniform, however, and supports the theory that the wear is the same per degree of curvature regardless of the degree of curve. Of this and many other phases of the subject of curvature very little is really known, but in so far as the evidence which has been collected indicates, these assumptions are approximately correct, and will be used for the purpose of determining as accurately as we can the value of one degree of curvature.

There has already been worked out a figure showing the average cost per train mile of operating expenses. In deriving this cost, all the elements of cost embraced in curvature, distance, grades, etc., were included. If then we could separate this statement in such a way as to show the portion directly chargeable to curvature, we would be enabled to derive a value per degree of curvature which would be an actual working value as applied to our particular railroad. Such a separation is well-nigh impossible, owing to the many elements besides curvature which make up the whole, and for a like reason it would be similarly difficult to separate any of the other elements. For this reason the problem is viewed from another standpoint. It is evident that the total train load which may be pulled by any engine will depend directly upon the total resistance, which in turn is composed of the combined resistances due to grades, curvature, and to uniform motion on a level tangent. Elsewhere in this report it has been decided that six pounds per ton represented at average velocities the resistance on level tangent. On what curvature will the resistance due to the curvature be equal to six pounds per ton? No mathematical solution is possible to this question, and it can only be decided by experiment. Wellington says .376 pounds per ton per degree is the minimum, and .5 pounds per ton per degree is a good average. This would represent six pounds per ton on a twelve degree curve. The Committee on Roadway of American Railway Engineering Association stated 0.8 pounds per ton per degree was a fair average, which would indicate six pounds per ton on a curve of 7 degrees and 30 minutes. Mr. J. B. Berry assumed in his work on the Union Pacific that the resistance due to curvature on a 12 degree and 30 minute curve was the same as level tangent resistance.

Prof. Webb says in part:-

"At what degree of curvature is the total train resistance double its value on a tangent? No one figure will be exact for all conditions. Train resistance varies with the velocity and with the various conditions of train loading even on a tangent, and the ratio of train resistance on a curve and on a tangent varies according to the conditions. As an approximate statement we may say that a train running at average velocity on a ten degree curve will encounter an extra resistance due to curvature which is about equal to the average resistance on a level tangent."

Thus among prominent engineers the question is very unsatisfactorily settled, and we find resistance figured anywhere from .4 pounds per ton to .8 pounds per ton. Elsewhere in this report in discussing the extent of curve resistance, it has been stated that .8 pounds per ton should be used in figuring compensation for curvature. This figure, however, as adopted is intended to be the highest curve resistance which will be developed, and not an average curve resistance, which experiments show is often very much less. In compensating for curves it is of course important to use a compensation for the highest resistance in order that compensation may always be ample. There are two reasons for adopting a figure of less than .8 pounds per ton for this investigation of the value of curvature. In the first place there are many speculative quantities to be dealt with and a factor of safety should be provided in the calculations. It will be seen later, and it is also evident on the face that the smaller the assumed resistance the less the value of one degree of curvature. Criticism of this view point might be made on the basis that by presenting smaller values than the true values, less consideration would be given to the reduction of curvature than its importance demanded. The only answer to such a contention is that the value of curvature is at its best a very speculative quantity, and that it would be better to lose a little money yearly by not reducing a certain amount of curvature, than to do useless work which would entail endless interest charges. Then as experience and experiment give us a better knowledge of the true values, we may go back to the doubtful places and make the changes at no greater expense than formerly, but without any room for doubts as to the results. The second reason for adopting a figure of less than .8 pounds per ton for this particular problem, is that the items which may be affected by curvature and the per cent each bears to the whole are figured on the basis of the average cost of operation, of which curvature, grades, etc., are all factors. For this reason we should introduce another factor of safety in order that we may not multiply the curvature factor twice in the results, and while we have adopted .8 pounds per ton per degree as the most reliable figure to be obtained as representing the resistance due to curvature, we will assume .5 pounds per ton per degree for the cost analysis. This figure is determined by a somewhat round-a-bout process based on the probable error in using the average cost per train mile figures, and then adding a liberal allowance for safety.

A mile of continuous 12 degree curve would represent 633.6 degree of curvature, or about one and two-thirds complete circles. There will be no doubt even in the mind of the most skeptical that it will cost a lot more to run a train around a mile of such track than it will on level straight track. If the tractive resistance is twice the average on a 12 degree curve and we can determine what items of operating expense are affected by doubling the tractive resistance, we may establish for a mile of 12 degree curve its added cost as compared to the cost of a mile of average operation, which we already know. In other words, if we can determine what items of operating expenses will be affected and to what extent, by doubling the tractive resistance, we will have derived the value per train mile of 633.6 degrees of curvature, from which we may in turn derive the value of one degree of curvature.

Below is a table compiled on this basis. For the sake of brevity only the items affected are given, but the statement is derived from same values previously given and based on annual report for fiscal year ending June 30, 1910. Following the table is a brief discussion of the manner in which the per cent of the different items affected was obtained. No separation of the items as affecting freight and passenger service is attempted. The reason for this is that our data is not sufficiently accurate to make any distinction between the two classes. The available figures all deal with the net results of the two classes of service, and it would be impossible to make an accurate separation.

Increase in Curvature and Its Effect On Operating Expenses.

The Value of 633.6 Degrees of Curvature.

Items Affected.	% Of Whole	Per Cent Affected	% Cost Incr. By Curvature
2.-Ballast	.17	33	.06
3.-Ties	3.21	200	6.42
4.-Rails	.52	266	1.38
6.-Roadway and Track	4.86	100	4.86
25.-Steam Loc.-Rep. Ren. & Depn	10.05	154	15.48
31.-Passenger cars-Repairs etc.	1.53	105	1.56
34.-Freight cars-Repairs etc.	6.70	83	5.56
82.-All fuel for road locomotive	9.49	50	4.74
83.-Water for road locomotives	.70	50	.35
84.-Lubricants-road locomotives	.24	30	.07
Totals	37.47		40.48

2.-Ballast:-No accurate data is available as to the greater amount of ballast necessary to keep track up on curves, but from statements of roadmasters and section men, it is determined that on curves of four degrees about ten per cent more ballast is applied than on tangent track, while on ten degree curves it is determined from the same source that about thirty per cent more ballast is applied than on tangent track. We may assume then with small error that a 12 degree curve will require about 33 per cent additional ballast.

3.-Ties:-Volumes have been written on the subject of ties, and their comparative life, but little or nothing has been written on the important question of their relative life on curved and straight track. And yet there is no question but that ties wear out faster on curved track than on tangent track. The fact is so well recognized that instructions are in effect on this railroad that all ties be tieplated with metal tie plates where the degree of curve exceeds a certain amount, depending principally on the volume of traffic and the class of track maintained. It is not entirely to protect the ties, however, that this is done, but also to prevent track from spreading, etc. But the greatest consideration is preservation of the tie and it is considered justifiable to spend fifteen cents per tie plate or thirty cents per tie to accomplish this end. On what on this railroad is known as class "A" track all curves of three degrees and over are to be tie plated. Class "A" track includes all main line track as distinguished from branch line track. If such expense for tie plates is justifiable, we might derive some figures indicating the relative wear on tangent and curved track. It can be saidthat the ties so protected wear as long as ties in tangent track.

It is estimated that the addition of metal tie plates will increase the life of a tie 50 to 100 per cent on a three degree curve. It might be supposed from this statement that on a six degree curve it would again double it, but such is not the case, and experience has shown that the life without tie plates will be very little less on the six degree curve than on the three degree curve. There are two reasons for this. If the curve is properly elevated for the speed, there should be the same weight or thrust against the outer rail in either case, and about two-thirds of the weight will be on the inner rail in either case. As the weight of the train is constant the net results should be the same. Theoretically the thrust against the outer rail should be zero if the track is correctly elevated for the speed. The rigid construction of the trucks prevents this, however, and the wheels on the outside of the curve bind or thrust against the rail due to the longer radius of the outer curve. The amount of such thrust will vary with the degree of the curve, being proportional to the angle between the center line of track and tangent to the curve at point of contact. The resultant force is transmitted through the rail to the ties and the ties are cut by the rail thereby. This cutting is greater on the outside edge of the base of rail than on the inside edge, causing a canting of the rail, and it becomes necessary to adze off the surface of the tie beneath the rail to return the rail to its proper bearing. All these things lessen the life of the tie. The tendency of engineers to slow up on sharp curves, thereby throwing more of the weight on the inner rail, is probably responsible to a large degree in keeping the mechanical wear of the ties on sharp curves little more than on light ones.

There is one other thing affecting the relative life on curves of different radii, and that is the speed. If the speed is proper for the elevation there will be no other effects than those already mentioned, but as the speed is greater, and such is often the case, then the mechanical wear will be greater because the thrust against the outer rail will be increased by the centrifugal force due to the higher speed than that for which the track is elevated.

The foregoing statements show the causes but do not clearly outline the effects. If the resultant pressure exerted on the ties due to curvature were applied in a plane parallel to the surface of the tie the increased wear would be very little more if any than the wear on tangent track. This is not the case, however, for the pressure is actually applied at the outer edge of the flange, so that the tendency is for the rail to revolve about that point as a center, and the bearing being uneven, the crushing strength of the fibre is exceeded on account of the load being applied at one point instead of distributed. The result is that a V-shaped section is soon worn in the face of the tie. To restore the bearing and prevent overturning of the rail the tie must be adzed, and the final result is that the tie is adzed until it is no longer fit to perform its duty in the track and must be removed. Tie renewal records show that the degree of the curve determines approximately the time the tie stays in the track and that it is approximately proportional to the degree of curve. This life will obviously depend also on the kind of wood in the tie or upon the crushing strength of the fibre, and also to a certain extent on the climatic conditions - that is, whether the tie is subjected to extremes of temperature and moisture. To overcome the effects of the concentrated loading metal tie plates are applied, so that the metal tie plate receives the application of the load and distributes it more evenly over the tie.

In practice it has actually been found that the adzing necessary to maintain a safe bearing of the rails on ten degree curves is about three times as great as on three degree curves, and that on ten degree curves ties last about five years without metal tie plates, whereas the average life of the same kind of ties on tangent track is about ten years.

In discussing the subject Mr. Wellington says in regard to the life of ties:-

> "Considerable observation and inquiry indicates that the following comes very near the average life of white oak ties on sand or gravel ballast, imperfectly drained."

On tangent ------------	9 years.
On 2° curve -----------	8 years.
On 6° curve -----------	7 years.
On 10° curve ----------	6 years.
On 14° to 16° curve ---	5 years.

These figures would not bear out a statement that the life on curves was directly proportional to the degree of the curve, and as has already been shown this is not expected to be the case. However, no tie fails directly and wholly by reason of curvature, and the table indicates plainly that curvature plays some part in tie renewals. If the decrease in life as shown for the two degree curve was carried out to the 14 degree curve the tie should last only two years according to Wellington's table. However, average curvature would not include curves of such short radius and under ordinary conditions we will find curves are usually limited to about four or five degrees, except in extremely few instances or unless the division be very mountainous. We must evidently derive an approximate figure to show the average relatively greater cost due to average curvature. In other words, while we are trying to arrive at the expense of 12 degrees of curvature per one hundred feet in our figures, our ultimate aim is the cost of any degree of curvature within ordinary limits, hence we should attempt to make our result such that it will apply to the curvature most prevalent on our particular railroad. This will of course introduce a slight error in that the figure will be too high for some curvature and too low for other curvature, but the error compared to the total value of curvature should be inappreciable. It is also evident in determining the effect of curvature on tie renewals we should base our figure for determining the decreased life for a twelve degree curve on the decreased life of ties on track with average curvature on this railroad. The concensus of opinion as alrady stated is that by protecting the tie with metal tie plates on a three degree curve the life is increased from fifty to one hundred per cent. It is of course true that ties on tangent track protected in the same manner would have their usefulness and life increased, and the records show that white oak ties last about fifty per cent longer by such protection. This is increased still more on treated ties, but as the number of such ties on curves is very small, we will use fifty per cent in our estimate. On a twelve degree curve then, the life should be increased 200 per cent. Then in determining the cost per degree our figures would indicate on a one degree curve for example, the additional per cent cost due to curvature is about 16 per cent and on a six degree curve 100 per cent. Within those limits the statement is probably very nearly correct, and our justification is that on the Frisco System ~~is~~ about ninety per cent of the curvature will fall between those limits, and in using the figure derived from the decreased life on a three degree curve, we are assuming conditions applicable to average curvature on the Frisco.

4.-Rails:-More reliable figures are obtainable as to the relative life of rails on curved track than could be found in estimating the comparative life of ties. From actual cases under observation on this railroad it has been found that on ten degree curves on class "A" track the outer rail must be renewed about every three years, the outer rail being then placed on the inside of the curve where it remains for six years longer. Or on an average the life of the two rails on a ten degree curve would be four and a half years. This rail taken from the outside of the curve will also last as long on the inside as a new rail placed on the inside. On tangent track it is estimated rail will last an average of ten years, ot the expense for ten degree curvature as compared to tangent track is 222 per cent. If the same ratio held on 12 degree curves the expense as compared to tangent track would be 266 per cent, or 22.2 per cent per degree of curvature. As compared to other writers it is found Wellington figured 30 per cent, Prof. Webb 22.6 per cent, and Mr. J. B. Berry 24.0 per cent.

Probably the most comprehensive data gathered and published from actual experiment is the work done on the Northern Pacific railroad by Prof. Webb. Special locations were selected and the loss in weight of the rail actually measured. This was done on tangent track and on both rails of curves varying between four and eleven degrees. The results were very uniform, and showed that on a curve of 7 degrees and 42 minutes there would be twice the wear on tangent track. This would indicate 26.0 per cent increase wear per degree, which is actual proof to substantiate the general statement above that the excess wear per degree is about 22.2 per cent.

6.-<u>Roadway and Track:</u>-This account is composed of several items, but the first two only are affected in any appreciable degree by curvature. These items are track maintenance and applying track material. It is customary to figure that a mile of three degree curvature will require about one-quarter more track work than a mile of tangent. A mile of twelve degree curve would not require twice as much track work, but the cost of relaying the rails, ties, etc., would probably balance up the cost, so that we would be safe in saying that these items of roadway and track would be increased four times as much, as on three degree curve or twice as much as tangent track. However we do not find in practice that any large increase in section labor is found on track with heavy curvature. The sections are made shorter, however, which in effect is the same as employing more labor. The relaying of rail is ordinarily done by an "extra gang", and costs about three hundred dollars per mile. On a ten degree curve if rail is relayed every four and a half years and on tangent every ten years, the extra cost per mile for laying rail alone one the curved track would be about four hundred and fifty dollars. There is yet one other consideration. Where the length of the sections and the number of section men employed is the same on straight and curved track, the standard of maintenance is certainly not the same, and the section with curved track suffers. This has often been the cause of changing the length of sections in an attempt to balance up the total amount of work required to secure the same standard of maintenance throughout.

25-26-27-Steam locomotives=Repairs, renewals, depreciation:-It has beem previously determined that of the 10.05 per cent of total operating expenses charged to this account, only 8.6 per cent was chargeable to repairs of road locomotives, so that in determining the value of curvature we must deal with only 8.6 per cent, as this is the only portion which will be affected by curvature, or it might be better to say that it is the only portion which will be affected by reduction of curvature. As already discussed, the portion of engine repairs which are caused by the effects of curvature is a question which has received very little actual investigation. On this railroad there has been practically no investigations except with flange oilers, which have reduced the tire renewals some.

In the table prepared by Wellington showing the distribution of the cost of engine repairs it was estimated 19.0 per cent of the total repairs were caused by the effects of average grades and curvature. The two contributing causes were stated to be additional wear on tires and wheels, and wear and tear on engine caused by additional power required. These figures were based on an assumption of 30 degrees of curvature per mile. On the Frisco the average curvature is 34 degrees per mile. If we assume one half, or 9.5 per cent of this added cost is due to curvature, which would seem to be a conservative estimate, we may say 34 degrees of curvature per mile will increase the operating charge to locomotive repairs 9.5 per cent. In a mile of continuous 12 degree curvature this per cent would be increased about 19 times, or repairs to locomotives would be 180 per cent of the average. This represents 154 per cent of the total cost of repairs. This method of arriving at the cost is very unsatisfactory and at best is more of a guess than anything else. However we had very good proof that rail wear was increased 266 per cent by reason of a mile of 12-degree curvature, and to say that engine repairs are only about half of this appears reasonable. It was also found that about one half of the destructive effects on track were caused by the locomotive and one-half by the remainder of the train. The destructive forces would be transmitted equally to engine and track so that one half the excess rail wear in per cent should about equal the excess tire and wheel wear in p per cent.

Repairs to Equipment:-There was deducted as in the case of locomotives certain per cents of the cost of each class of equipment which were chargeable to curvature. By following out the same line of reasoning as in the case of engine repairs, the excess cost of a mile of 12 degree curvature will be derived. In the case of equipment, however, instead of assigning 50 per cent of the estimated cost of curvature and grades to curvature, it is estimated only 25 per cent will be increased by curvature. The reason for this is found in the relative cost of repairs of draft gear, brake rigging, the cost of brake shoes, etc., as compared to the cost for new wheels to replace those with worn flanges and treads. Even with the detailed cost figures which are kept by the mechanical department, and which show the actual expenditures in great detail, there must necessarily be a great deal of assumption as to the correct separation of the contributing causes which go to make up the repairs as a whole. The repairs to work equipment will not be considered. The cost is very small and probably 95 per cent of repairs are attributable to other causes than curvature.

Transportation Expenses:- That curvature will have some effect on trainmen's wages must be conceded. It is only in cases of overtime pay that such will be the case however, and then only because it will reduce the time of trains to a slight degree. Our consideration of the problem, however, is a general one and uncertain factors should be eliminated in so far as possible. In specific cases where the overtime element might assume very appreciable proportions the proper consideration should be given to it.

The fuel, water, and oil bills will be the only items ordinarily affected by curvature. We previously decided that direct average hauling of the train consumed 50 per cent of the fuel. As we also have assumed a mile of 12 degree curvature to offer the same resistance as a mile of ordinary pull on level tangent, we may say directly that the increased cost of a mile of 12 degree curvature will be fifty per cent. The same figure was determined for water and thirty per cent for oil. It is stated by the mechanical department that the use of flange oilers has decreased the flange cutting very materially on the engines so equipped, and that the saving more than pays interest on the cost of installing these devices and the oil used. If this statement proves to be true it may, change some of the figures assumed when all engines are so equipped, but as yet no actual figures have been given out in support of the statement.

SUMMARY AND CONCLUSIONS.

From the table derived it is seen that 37.47 per cent of the total operating expenses will be affected in some degree by curvature, and that 633.6 degrees of curvature will increase the cost per train mile 40.48 per cent. The average cost per train mile was found to be $1.29, so that the value of 633.6 degrees of curvature would be 40.48 per cent of $1.29 or $.52. In the beginning of the discussion it was stated that the value per degree of curvature would be derived on the basis that the value per degree of curvature was the same regardless of the degree of the curve, within the limits of ordinary or average curvature. The value of one degree of curvature then would be 1/633.6 of $0.52, or $0.00082. The value of one degree of curvature per daily train per year would be 365 x $0.00082, or $0.30. Some writers have figured a value for curvature on compensated grades. It seems better however to omit this distinction, as the value of any two lines may be figured independent of such calculations.

It was admitted in the beginning of the discussion that the value derived per degree of curvature would be too high. To show that the error will be very small we may figure as follows. On the Frisco the average curvature is 34 degrees per mile, which is one-nineteenth of the amount assumed in our calculation. If the calculations for the 633.6 degrees of curvature are based on an actual curvature of 34 degrees, the error can be only about five per cent. Again, it was found that only 40.48 per cent of operating expenses were increased by 633.6 degrees of curvature, hence in assuming the cost per t train mile as being the average including the 34 degrees of curvature per mile, the final error can only be 40.48 per cent of five per cent, or about two per cent.

It may also be shown that the value of eliminating ordinary curvature is quite small compared with other reductions in the way of distance and grades, and that even quite large errors entering into the calculations of the value of curvature will not in ordinary cases involve a very considerable amount of money. For example, suppose we consider the value of eliminating three hundred feet of a six degree curve where the total daily train movement is ten trains. Three hundred feet of a six degree curve would contain 18 degrees of curvature, worth per daily train as already calculated $0.30, or a total of $5.40. For ten trains this would amount to $54.00 which capitalized at 5 per cent would show a justifiable expenditure of $1080.00. Suppose now in determining the value of our 633.6 degrees of curvature our figures should have been increased 20 per cent. The final figure would be $1240.00 instead of $1080.000

In discussing the value of distance as affecting operating expenses reference was made to the work of reducing the distance and curvature at Mile 131.5 on the Eastern Division. It was stated the cost of the work was estimated to be $9500.00, of which $1100.00 was a charge to additions and betterments. The direct object of the work is the elimination of a very bad ten degree reverse curve, which has been the cause of several serious derailments. The total curvature to be eliminated is 88 degrees. it was found that incidental to the reduction in total curvature the distance was shortened 60 feet. This reduction in distance according to our previous figures justified an expenditure of $744.88. The value of the reduction of curvature may be figured as follows:- We found the value of one degree of curvature per daily train per year was $0.30. At the point in question there are twenty-eight daily trains. The yearly saving due to the elimination of the 88 degrees of curvature would then be 88 x 28 x $0.30 = $739.20. This capitalized at five per cent would represent a justifiable expenditure of $14,784.00.

With the saving in distance the total justifiable expenditure would be $15,528.88, whereas the actual cost is only $9,500.00. The owrk then is fully justified merely as a saving by reason of reduction in curvature, without any consideration of the saving which will unquestionably be made in eliminating the frequent derailments. This case is given because it shows clearly that there are cases where it is justifiable to eliminate curvature without any other consideration. It will be found however that these cases are the exception and not the rule, unless some extremely poor locations have been made, and it will also be found that in the majority of cases where such work is economical the curvature reduced is very heavy as in the case cited.

One other consideration should be given the use of curvature, and that is its limiting effects on train load. We have seen that a twelve degree curve doubles the ordinary level tangent resistance. The momentum of a train will carry it around a given amount of curvature, but of course there will be a limiting point to this, and a long curve of any radius may determine the train load over that piece of track if its effect is to increase the total train resistance after allowing for the effects of velocity. The particular location of the curve should then be studied and if it is such that it becomes a controlling factor in train load its value will not only be the value of curvature but the value of the additional train mile as well. It has been stated that curvature may prohibit the use of heavy engines. This has actually been demonstrated on our own lines in the attempted use of the Mallett type of engines on the Eastern Division. It cannot be said that curvature was directly the reason for their removal, but it was a large factor in the decision to take them off the division. It was found that the curvature was one of the greatest causes for an unusual amount of repairs, which kept the engines in the shops a great part of the time. Sharp curvature may impede the speed of trains by making it necessaryto check the speed on the curve, or if the curves are close together to maintain an average speed on tangent which will be commensurate with the safe speed on the curves, it being impossible in such cases to run faster on the tangents as they are so short that insufficient time is given for in-creasing and then de-creasing the speed. Necessity for such a consideration will only be found in isolated cases, although it will often be found that an excessive amount of curvature will appreciably lengthen the time on the division. This is true of the Eastern Division of the Frisco.

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Locomotive Tractive Power.

Before taking up the question of the tractive power of locomotives a few simple explanations and definitions bearing on the subject may tend to simplify the discussion.

The locomotive engine stated in as few words as possible, is composed of a fire tube boiler and fire box mounted on the same frame with a simple or compound engine, the fly wheels of which are the driving wheels, and the track may be considered as the belt. As the track or belt is fixed and the engine free to move, the effort of the cylinders in turning the fly wheels is converted into motion of the engine itself along the track.

In order to produce this motion there must be three essential elements or units:-

1.-The boiler or steam producing element.

2.-The cylinders, or work producing element. The cylinders may be considered merely as a mechanical means of transforming the energy of the steam into work, and the wheels, connecting rods, etc., as a portion of the same x unit, as they are all necessary to produce the distance factor in producing work, which in turn is measured by force times distance.

3.-The weight on the drivers or the adhesion element. This is taken as the total weight on the rail at the point of contact of the drivers. It does not include the weight on the pony trucks or trailing wheels.

As will be seen later the tractive effort available at the drawbar will depend on the weight on the drivers, and the weight which may be placed on the drivers will depend in turn on the supporting powers of the foundation, or in other words the track. If the rails were capable of sustaining any weight or load, no matter how great, the weight of the engine could be increased indefinitely, and the economical limit would only be determined by the capacity of the boiler to create energy enough to move such a locomotive at the required speed. However, the weight which may be placed on the drivers is determined by the weight which may be safely placed on the track. In America it has been the custom of late years to figure on 60,000# axle load for a track laid with 100# per yard rail. This would be a wheel load of 30,000 lbs. or 3000 lbs. per 10# per yard rail section. The Pennsylvania Railroad has recently constructed a simple Mallet engine using superheated steam, with 64,000# axle load. Ordinary practice would demand that such an engine run on rail weighing at least 110# per yard. It is understood that this engine will operate on a divisiov laid with rail weighing 90# per yard.

The controlling factor in locomotive design will be first of all, then, the amount of weight which may be placed on a driver. There may be an unlimited number of drivers theoretically, but practically the number will depend on the speed which the engine is required to make, and on the length of the engine when completed. The latter feature is a controlling one because there is a limit to the length of boiler which may be condtructed and operated successfully. This limit has been very nearly attained in the Mallet type of engine where the tu-bes are about twenty-four feet long.

All these different features have been embodied into numerous designs and usually classified according to the number and arrangement of the wheels. The different designs are the result of different requirements as to speed and tractive effort, as well as individual ideas as to design, and no general discussion would serve to show the advantage or disadvantage to be derived from any particular type. The requirements for each case will determine the most economical type to use, and in another part of this report, where the question of speed of trains is taken up, there will be found a discussion bearing on this phase of the subject.

If there were no friction between the driving wheel and the rail at the point of contact, it is evident that the wheel would simply slide on the rail while turning and no motion along the track would result. Friction does exist, however, and is caused by an actual interlocking or meshing of the particles composing the wheel and rail, similar to the meshing of cogs in a train of gears. As long as there is no motion between the surfaces in contact, which means so long as the wheel simply rolls along the rail without sliding, the friction is called static friction. If, however, the surfaces in contact have a motion with respect to each other so that there is destruction of energy, the friction is called dynamic friction. The first or static friction is the friction between the driving wheels and rails which permits the train to be propelled. The second or dynamic friction is the friction between the wheel and rail when the wheel is sliding, or the friction between the brake shoe and the wheel when brakes are set, or between the side of the ball of the rail and a sharp flange, and is all converted into heat or into work of tearing loose portions of the surfaces in contact. If this heat could be conserved and put back into the boiler, it would again be available for drawing the train or for any other use to which the steam might be put.

If we consider for a moment an engine on level track and fastened at the tender by a train or otherwise so that it cannot move, we know that if sufficient steam is admitted into the cylinders the driving wheels will slip and begin to spin around rapidly. The measure of the resistance to such slipping is called the co-efficient of friction. This co-efficient will vary with different bodies depending on their molecular structure, and is the ratio of the force necessary to slide the body compared to or divided by its weight. Its determination is entirely a matter of experiment. For steel, dry, clean and bright, the co-efficient is about one-third. Under ordinary conditions of the atmosphere where some moisture is always found on the rail , the co-efficient is very nearly one-quarter. Where the rail is very wet or greasy the co-efficient is sometimes lower than one-fifth. Technically the co-efficient is one-third, for when water or oil is introduced between the surfaces the effect is to put little rollers between them and the co-efficient is not the co-efficient for steel on steel, but is rather a measure of the co-efficient between water and steel or oil and steel. Under the most favorable operating conditions dynamometer tests have indicated a co-efficient of very nearly one-third, but this is seldom attained. In fair weather tests show that one-quarter is a very nearly uniform expression of the co-efficient of static friction and this figure is almost universally used in the United States. So long as the weight on the drivers remains constant the force necessary to slide the wheels remains constant regardless of the speed, so that the co-efficient of friction is in no way dependent on the speed. If a driving wheel strikes an obstruction on the rail, such as dirt or a high rail joint, the wheel may be temporarily lifted from the rail, in which case the weight of the boiler and remainder of the engine is thrown onto the remaining drivers. The total weight may then be momentarily decreased by the weight of the one driver, in which case the force necessary to slide the wheels will be slightly diminished and the wheels may slide. If the accelerating force is great enough this slipping may continue as the friction is temporarily changed to dynamic friction, the co-efficient of which may be as low as one-tenth. This change is more likely to occur when the full power of the engine is being exerted and for some time lead to the conclusion that the co-efficient of static friction was less at high speeds. Careful experiments have disproven this however, and it is no longer considered.

It is apparent from what has been said that the maximum pull an engine may exert will be expressed by the weight on the drivers multiplied by the co-efficient of static friction. If the cylinder power, or work producing element is capable of producing a greater pull, the excess power will evidently be unavailable, for all it can do is to slide the driving wheels on the rails. it is customary in designing locomotives to make the cylinder capacity somewhat greater, however, in order to obtain the full power when conditions are favorable, or to offset slight drops in steam pressure, etc.

In order to distinguish the draw bar pull or tractive effort which may be obtained at the back of the engine due to the weight on the drivers from that draw bar pull or tractive effort which may be obtained from the cylinder, the former is ordinarily termed the tractive effort by adhesion, and the latter the tractive effort by the cylinders. If the tractive effort by adhesion were always available for drawing the train this problem would be greatly simplified, but such is not the case. While the cylinder capacity may be made great enough to develop the full tractive power of adhesion at all speeds, it has been found uneconomical to increase the size of the boiler and fire box to such an extent that this is practicable. The reason for this lies in the fact that while at ordinary speeds or average speeds the full tractive power of adhesion may be obtained with boilers of a certain size and steam generating capacity, at higher speeds the consumption of steam is so great that the boiler would have to be increased out of all proportions to the demands made upon it ordinarily, and there would consequently be a great loss of energy at the average speeds. The most economical size of boiler will evidently be one capable of supplying to the cylinders the steam necessary to develop the full tractive power of adhesion at the speed for which the locomotive is designed. It will be seen that the maximum available tractive effort of a locomotive is the tractive effort of adhesion. Rack and pinion devices have been used in special cases, such as on the Pike's Peak Cog Road, in order to get greater tractive power than may be obtained by adhesion. These devices are of course not to be considered on ordinary railroads, so the original statement needs no qualification.

Whenever the cylinders are producing less work than is necessary to slide the wheels, the available tractive effort will evidently be expressed by the tractive power by the cylinders, and the following discussion deals with this phase of the subject.

The equation expressing work is--

$$W = f\ s$$

in which f=the force acting and s=the distance through which it acts. If f = steam pressure it is ordinarily expressed in pounds per square inch, and s would then be an expression of the distance in inches through which the force f acts.

For convenience we may let f = boiler pressure in pounds per square inch, and s = the piston travel in inches. Also let

D = diameter of driving wheels in inches.
d = diameter of cylinders in inches.

We may then write the following equation as an expression of the work performed by one piston in a single stroke, the result being expressed in inch pounds,

$$\frac{f\pi d^2 s}{4}$$

and the work done in one complete revolution of the drivers, if the engine be a simple two cylindered engine is four times as great or would be expressed by

$$W = f\pi d^2 s.$$

Since the space traversed in performing this work is the same as the circumference of the drivers or πD, the force acting at any point of the revolution would be

$$\frac{f\pi d^2 s}{D}$$

which is the fundamental expression of the tractive effort of the cylinders. The equation may be simplified by dividing both terms by π, and will then read;

$$\text{Tractive effort by cylinders} = \frac{f d^2 s}{D}$$

The formula above given is sometimes called the formula for the theoretical tractive effort of the cylinders, as it assumes that the steam pressure is the same as the boiler pressure and that it remains constant throughout the stroke. The internal friction of the moving parts is also neglected. Actually the full boiler pressure cannot be realized above piston speeds of about 250 feet per minute, as the steam cannot get into and out of the ports at a faster speed, and it is necessary to close the steam inlet port at a point before the full stroke, both to obtain the expansive value of the steam as well as to leave only a small back pressure for the piston to work against on the return stroke. For piston speeds below 250 feet per minute the formula may be used as written, but for piston speeds greater than 250 feet per minute it has been found that the average available pressure or as it is commonly called, the mean effective pressure, becomes less as the speed increases. In stead of tractive effort, "Indicated Tractive Effort" is somestimes written, because the amount of the tractive effort is indicated not by the boiler pressure but by the mean effective pressure. To correct the formula so that it may apply to all speeds, we may write M. E. P., or mean effective pressure for the term f, and the equation will be--

$$I.\ T.\ F. = \frac{M.E.P.\ d^2 s}{D}$$

There is a small error in the equation due to not considering the reduction in piston area caused by the piston rod. This error is commonly neglected, however, and is probably more than offsetted in the wear of the cylinders after the engine has run a few hundred miles.

The theoretical ratio of the mean effective pressure to the boiler pressure may be calculated for any engine by making proper allowances for end clearances, condensation, back pressure and friction, but the method is complicated and the results not very satisfactory. The expansion actually does not follow Mariotte's law pv=a constant, owing to reduction of temperature which introduces other errors. For these reasons the most accurate results are obtained from taking careful measurements from indicator cards. It is presumed the taking of these cards and calibration are too familiar to need explanation. As the results obtained show the actual pressure of the steam at all times, no correction for friction in the steam passage or other parts is necessary, and the only correction which needs to be made is for end clearance. This can be measured with considerable accuracy by taking off the cylinder head, or is obtained from the specifications of the engine. However, unless a very careful study is being made of the performance of some particular engine, this end clearance may also be neglected as its effect on the indicator card will be very small, the tendency being to give a better expansion indication than is actually obtained.

It has been stated that for piston speeds below 250 feet per minute the M. E. P. may be considered as constant, while for piton speeds greater than 250 feet per minute the M.E.P. decreases with the speed. Up to this point the maximum efficiency of direct pressure and expansion may be obtained, but when the speed increases over 250 feet per minute, the speed and the rate of expansion of the steam, the friction and wire drawing through the ports and the back pressure all come into play. It then becomes necessary to reduce the time of cutoff to conserve the supply of steam and to prevent too high back pressure during the exhaust. The steam also has less time to get through the ports and into the cylinders, and consequently less time to get out after its work is performed. These facts combine to reduce the amount of available working pressure.

A number of railroads, notably the Southern Pacific and the Pennsylvania, have carried on extensive tests to determine the ratio of mean effective to boiler pressure at different speeds. The American Locomotive Company has also taken a prominent part in this investigation and has published several pamphlets and tables bearing on the subject. In calculating their results the American Locomotive Comapny has adopted a figure of 85% as the mean effective pressure for piston speeds of 250 feet per minute and less, and has prepared a speed factor curve or table from which the tractive power at higher speeds may be obtained by multiplying by a proper factor. These speed factors are derived from a curve representing the drop in M. E. P. at increased piston speeds on the basis that the M.E.P. is 85% of boiler pressure for piston speeds of not more than 250 feet per minute. The mechanical department of the Frisco has adopted these tables until such time as they may be able to carry on extensive tests of their own.

In volume two of the American Railway Engineering Association Proceedings published in 1910, there is published a paper by Messrs. John D Isaacs and E. E. Adams of the society dealing with "Tonnage Rating". In this paper there is given a compilation in the form of a curve diagram, of the results of well known experiments to determine the ratio of mean effective pressure to boiler pressure at various piston speeds. Messrs. Isaacs and Adams have also presented in this paper a straight line formula which they themselves use and which is a very fair average of the curves given. A reprint of this diagram is given here as Fig. C, and in addition there has been platted on the diagram the calculated curve of the American Locomotive Comapny. It should be stated that this curve is not given by the American Locomotive Company, but the figures they present indicate the curve which is given. Reference to the diagram shows that few of the experiments showed as high as 85% of boiler pressure at low speeds. The Pennsylvania assumed not over 80% in their tests at the St. Louis Exposition. Unfortunately it is not possible to present their reasons for doing this. In discussing their adoption of the straight line formula

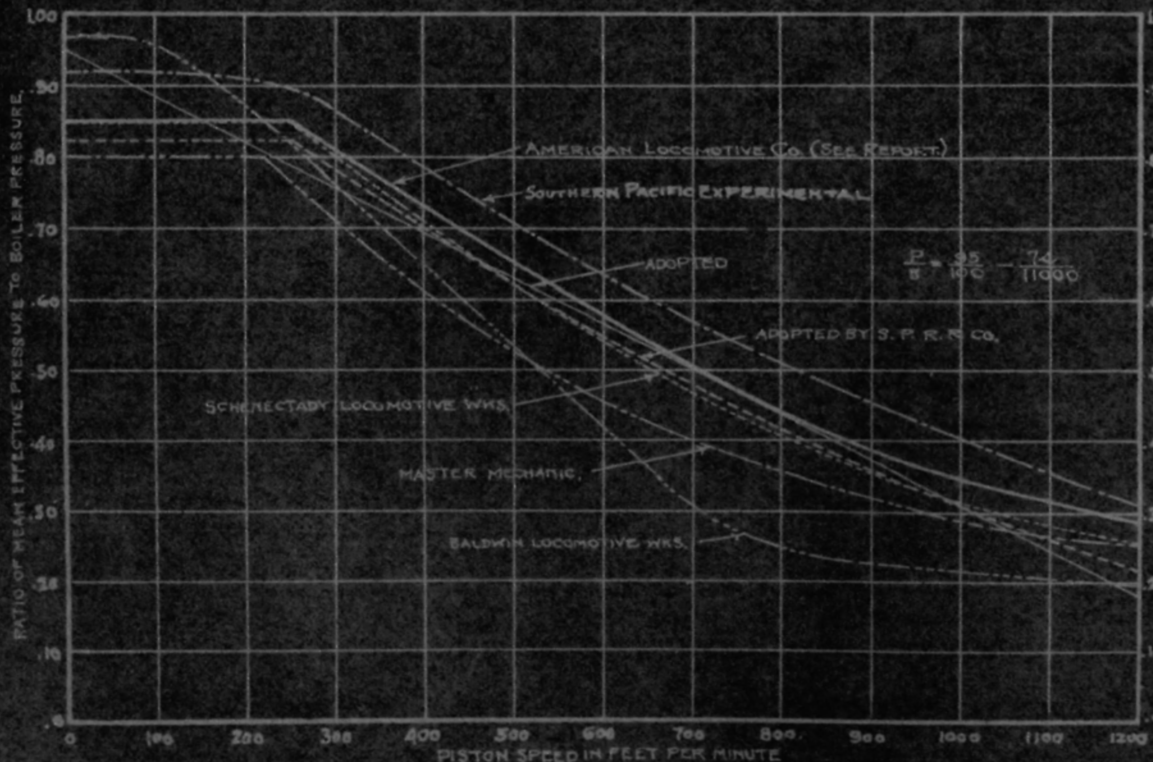
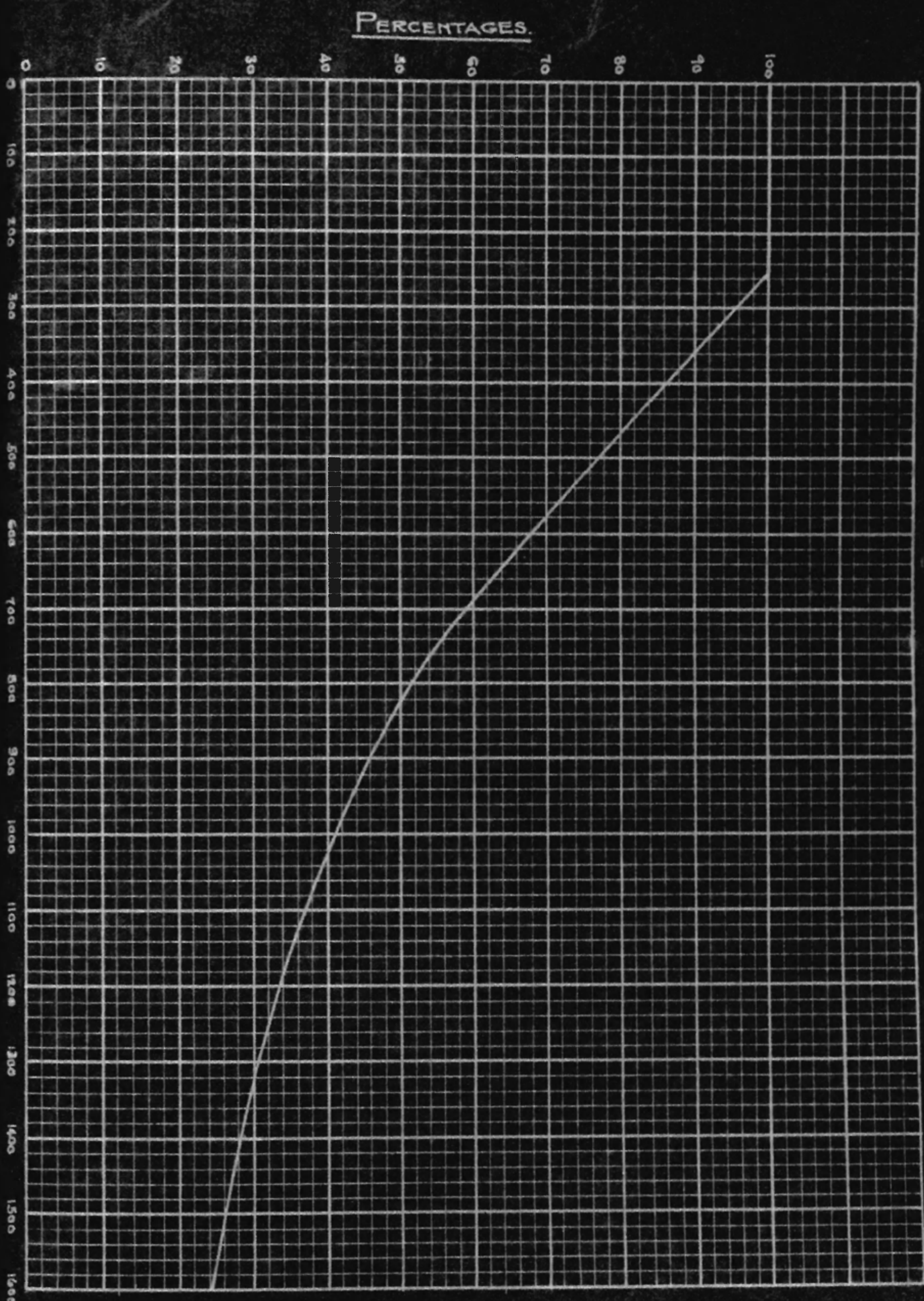


FIGURE C.– CURVES SHOWING RATIO OF MEAN EFFECTIVE PRESSURE TO BOILER PRESSURE IN SIMPLE ENGINES.– REPRINT OF TABLE BY J.D. ISAACS AND E.E. ADAMS IN BULLETIN 112 A.R.E.& M. OF W. ASSOCIATION.

Messrs. Isaacs and Adams say in part:"The ratio of mean effective pressure to boiler pressure at various speeds is taken as a straight line to simplify the mathematics. It will be noted from the diagram that this line corresponds very closely with the curve adopted by the Southern Pacific Company, which in turn was drawn as an average of the curves given both by experimental work and other authorities. Here again we notice such a considerable difference in data that our straight line appears to be as nearly an average as any curve." While it is true that the straight line curve follows the Southern Pacific curve very closely above piston speeds of 400 feet per minute, at speeds of 250 feet per minute and less there is a great variation. The straight line formula at 250 foot speeds corresponds very closely to the 80% used by the Pennsylvania, however, and if it is assumed that the minimum piston speed will be 250 feet per minute, the straight line formula will as stated be a very fair average of all the results. The calculated curve of the American Locomotive Comapny is practically parallel to the curve of the Southern Pacific Compny, but shows about two per ce-nt higher M.E.P. throughout.

As the figures of the American Locomotive Company have been accepted by the Mechaical Department of this railroad, and as they conform very closely to the very carefully made experiments and accepted figures of other large railroad companies, they will also be accepted in



SPEED FACTOR CURVE.

FIG. D

FROM AMER. LOC. CO.
BULLETIN # 1002.

Table IV. - Speed Factors.

Piston Speed Ft. Per Min.	Speed Factor	[redacted] Ft. Per Min.	Speed Factor	Piston Speed Ft. Per Min.	Speed Factor	Piston Speed Ft. Per Min.	Speed Factor
250	1.000	400	.863	550	.727	700	.590
255	.995	405	.859	555	.723	710	.582
260	.990	410	.854	560	.719	720	.574
265	.985	415	.849	565	.714	730	.566
270	.980	420	.844	570	.709	740	.558
275	.976	425	.840	575	.704	750	.550
280	.972	430	.836	580	.700	760	.542
285	.967	435	.831	585	.695	770	.534
290	.963	440	.826	590	.690	780	.528
295	.959	445	.821	595	.685	790	.522
300	.954	450	.817	600	.680	800	.517
305	.950	455	.813	605	.676	825	.502
310	.946	460	.809	610	.672	850	.487
315	.941	465	.804	615	.668	900	.460
320	.937	470	.799	620	.664	950	.436
325	.932	475	.795	625	.660	1000	.412
330	.927	480	.790	630	.656	1050	.392
335	.922	485	.786	635	.651	1100	.372
340	.917	490	.782	640	.646	1150	.355
345	.912	495	.777	645	.641	1200	.337
350	.908	500	.772	650	.636	1250	.322
355	.904	505	.768	655	.632	1300	.307
360	.900	510	.764	660	.628	1350	.295
365	.895	515	.759	665	.623	1400	.283
370	.890	520	.754	670	.618	1450	.272
375	.886	525	.750	675	.614	1500	.261
380	.882	530	.746	680	.610	1550	.251
385	.877	535	.742	685	.605	1600	.241
390	.872	540	.737	690	.600		
395	.868	545	.732	695	.595		
400	.863	550	.727	700	.590		

From Bulletin #1002 Amer. Loc. Co. and by Interpolation.

T.F. representing the tractive effort by the cylinders available at the drivers, and for any desired speed may then be written,--

$$T.F. = \frac{d^2 s\ K\ F\ 85}{D},\ \text{where}$$

T.F. = tractive effort in pounds.
d == Diameter of cylinders in inches.
s = Piston stroke in inches.
D = Diameter of drivers in inches.
K = Multiple of 100# boiler pressure.
F = Speed factor, above 250 foot piston speed.

In determining the tractive effort at any desired train speed it will first be necessary to know the relation between train speed in miles per hour and piston speed in feet per minute in order to select the proper speed factor, which is based on piston speed in feet per minute. A simple formula describing this relation may be derived as follows:-

Let S = Piston speed in feet per minute.
D = Diameter of driving wheels in inches.
s = Piston stroke in inches.
T = Train speed in miles per hour.

The distance traversed by one revolution of the drivers will be expressed by--

$$\frac{\pi D}{12}$$

and the distance in feet traversed by the piston during one revolution of the drivers will be expressed by--

$$\frac{2s}{12}$$

The piston travel in feet compared to the train travel in feet will then be expressed by the ratio--

$$\frac{2s}{12} : \frac{\pi D}{12},\ \text{or}\ \frac{2s}{\pi D}$$

One mile per hour corresponds to 88 feet per minute, so we may write the ratio-

$$S = \frac{2s\ 88\ T}{D}, \text{ OR}$$

$$S = \frac{56\ T\ s}{D},$$ which is the ratio or equation expressing the relation between train speed in miles per hour and piston speed in feet per minute.

For convenience table V is given, showing the relation between piston speed in feet per minute and train speed in miles per hour between 10 and 60 miles per hour for all combinations of stroke and driving wheels found on Frisco road locomotives. This table will be useful in computing the tractive effort of the different engines at different speeds. After the piston speed is determined the speed factor corresponding may be selected from table IV or Fig. D for simple engines and from Fig. E for compound engines. It must be remembered that table IV is based on the M. E. P. for piston speeds up to 250 feet per minute being 85% of boiler pressure, hence the speed factor at 250 feet piston speed is 1.00. In Fig. E the speed factor refers to the per cent of boiler pressure,

The study of the available tractive effort of compound locomotives is somewhat more difficult than that of the simple locomotives, especially at higher speeds. In two cylinder compounds the exhaust from the high pressure cylinder is usually the initial pressure of the low pressure cylinder, which makes it at once apparent that the curve of mean effective pressure will follow a different line. The two cylinder compounds are also designed in such a way that they may be worked simple when starting or at slow speeds. The valve arrangement is such that when simpled the high pressure cylinder exhausts into the air, and the low pressure cylinder uses steam from the boiler, but which has had its pressure reduced by a special valve. The design and working of this valve is such that the total work done by the high and low pressure cylinders is the same as nearly as may be, in order to prevent racking. The tractive effort when working simple would be expressed by the same formula as for the simple locomotive, the factor d being the diameter of the high pressure cylinder. When working compound the pressure in the high pressure cylinder will be offset to a certain extent by the back pressure in the low pressure cylinder.

The equation expressing tractive effort of two cylinder or cross compound engines working compound at slow speeds is usually taken as

$$T.F. = \frac{c^2 s \; 2/3 \; P}{D}$$

in which c = diameter of the high pressure cylinder. Working pressure is assumed as 2/3 boiler pressure to offset back pressure in low pressure cylinder. This formula is only approximate and the correct method of determining the T.F. would be by means of indicator cards to find the M.E.P in each cylinder, and then to compute the work of each cylinder separately. The Southern Pacific has adopted curves of M.E.P. for high and low pressure cylinders for different piston speeds. At 250 feet per minute piston speed the ratio of M.E.P. to boiler pressure in high pressure cylinder was adopted as 70% and the ratio of M.E.P. to boiler pressure in the low pressure cylinder was adopted as 34%. As a comparison, the tractive effort of the two cylinders of a two cylinder compound with high pressure cylinder 22" x 26" and low pressure cylinder 35" x 26", would be as follows, assuming 200# boiler pressure, 63" drivers, and piston speed of 250 feet per minute:-

By first formula, or ordinary formula--

$$T.F. = \frac{c^2 s\ 2/3\ P}{D},$$

$$T.F. = 26600\#$$

By calculating tractive effort of each cylinder separately,-- T.F. for high pressure cylinder would be expressed by formula---

$$T.F. = \frac{c^2 s\ 70\ P}{2D}$$, from which fromula the tractive effort of high pressure cylinder would be 13980#.

T.F. for low pressure cylinder would be expressed by by formula---

$$T.F. = \frac{c_1^2\ s\ 34\ P}{2D}$$, from which formula the tractive effort of low pressure cylinder would be 17190#, making the total tractive effort by the second method 31170# or about 17% higher than by the first method.

One of two things is indicated, either one of the formulae is incorrect or the low pressure cylinder is not correctly designed for that speed. The specifications of the engine given are for Frisco engines #700 to #704. If the first formula is correct and the engine design correct, the M.E.P. curve of the Southern Pacific is incorrect.

If we make substitution in the formulae for the same engine assuming a speed of twenty miles per hour, or a piston speed of 462 feet per minute, the tractive effort by the first formula will be the same or 26600#, and by the second 9490# for high pressure cylinder and 12400# for low pressure cylinder or a total of 21890#. If we apply the speed factor previously derived to the result from the first formula the corrected tractive effort would be 21550# or practically the same as the Southern Pacific formula gives. It appears in this particular case that the low pressure cylinder is somewhat too large. Calculations made for other types of Frisco compound engines show approximately the same tractive effort from the two cylinders at speeds of around fifteen and twenty miles per hour.

In the absence of original experiments and for the purposes indicated in this report, the M.E.P. curves of the Southern Pacific will be accepted, as they are based on actual calibrations from indicator cards. A reproduction of these curves is given as Fig. E. The formula to be used in calculating the tractive effort of a two cylinder compound or a cross compound will then be expressedin final form as---

$$T.F. = \frac{C^2 s\ R\ P}{2D} + \frac{c^2 s\ R_1\ P}{2D}, \text{ in which}$$

T.F. = Tractive effort in pounds.
C = Diam. in inches of high pressure cylinder.
c = Diam. in inches of low pressure cylinder.
s = Piston stroke in inches.
D = Diameter of drivers in inches.
P = Boiler pressure.
R = Ratio of M.E.P. to boiler pressure in high pressure cylinder.
R_1 = Ratio of M.E.P. to boiler pressure in low pressure cylinder.

In calculating the tractive effort of four cylinder compounds the same discrepancies will exist as in the case of the two cylinder or cross compound engine, unless proper value of M.E.P. is used. The formula usually given for the four cylinder compounds is--

$$T.F. = \frac{C^2\ s\ 2/3\ P}{D} + \frac{c^2\ s\ 1/4\ P}{D}$$

in which C and c are the diameters of the high and low pressure cylinders respectively. The same mean effective pressure curves will apply to the four cylinder compound, which in reality is simply a double two cylinder compound, and the equation of the tractive effort when working compound may be written:--

$$T.F. = \frac{C^2 s\ R\ P}{D} + \frac{c^2 s\ R_1 P}{D},$$

the factors being the same as in the case of the two cylinder compound.

Table VI gives the principal dimensions and weights

TABLE VI - SHEET 1 - FRISCO ROAD LOCOMOTIVES.

ENGINE #	DIAM. CYL. INCHES	STROKE INCHES	DIAM. DRIVER INCHES	BOILER PRESSURE	WEIGHT ON TRUCK	WEIGHT ON DRIVERS	WEIGHT ON TRAILER	TOTAL WT. ENGINE	TOTAL WT. TENDER EMPTY	TOTAL WT. ENGINE AND TENDER	WATER CAP. GAL.	COAL TONS.
26-27	17	24	64	135	25250	46550	—	70800	76700	147500	3700	8
29	17	24	59	135	25250	45550	—	70800	76700	147500	3700	8
31	17	24	64	135	31000	46000	—	77000	76700	153700	3700	8
32 & 33	17	24	64	135	25250	45550	—	70800	76100	147500	3700	8
34	17	24	64	135	29500	45500	—	75000	76700	151700	3700	8
35	17	24	64	135	28000	48000	—	76000	76700	152700	3700	8
38 & 40	17	24	64	135	25250	45550	—	70800	76700	147500	3700	8
43	17	24	59	135	28000	48000	—	76000	76700	152700	3700	8
44	17	24	64	140	31550	49700	—	81250	76700	157900	3700	8
45-46-47	17	24	64	140	29700	49300	—	79000	76700	155700	3700	8
48 to 50-51-52	17	24	63	140	30000	50000	—	80000	68000	148000	3700	8
53	17	24	63	145	30000	54000	—	84000	68000	152000	3700	8
54-56-57-58												
59-60-62-63	17	24	61	135	27200	52000	—	79200	58100	137300	3300	8
64	17	24	63	135	27200	52000	—	79200	58100	137300	3300	8
65-67-68	17	24	61	135	27200	52000	—	79200	58100	137300	3300	8
69-70-72 to 74	17	24	64	135	27200	52000	—	79200	58100	137300	3300	8
75	17	24	63	135	27200	52000	—	79200	58100	137300	3300	8
78 to 90	17	24	63	135	27200	52000	—	79200	58100	137300	3300	8
91	17	24	64	135	28000	55600	—	83600	85300	168900	4000	8
92	17	24	63	135	26700	45900	—	72600	70000	142600	3700	7
93	17	24	59	145	31750	50750	—	82500	82000	164500	3800	8
94	17	24	64	155	36100	62800	—	98900	90200	189100	3800	8

Table VI - Sheet 2 - Frisco Road Locomotives.

Engine #	Diam. Cyl. Inches	Stroke Inches	Diam. Driver Inches	Boiler Pressure	Weight On Truck	Weight On Drivers	Weight On Trailer	Total Wt. Engine	Total Wt. Tender	Total Wt. Engine And Tender	Water Cap. Gal.	Coal Tons
95	17	24	59	150	28000	52000	—	80000	82000	162000	3600	7
96 to 103	17	24	63	150	32000	56000	—	88000	82000	170000	3600	7
104	17	24	61	150	26000	58000	—	84000	66000	150000	3000	8
106-107	17	24	63	135	26000	48000	—	74000	58000	132000	3000	8
108 to 113	17	24	63	150	32100	52500	—	84600	74000	158600	3000	8
114-115	17	24	63	160	31000	62000	—	93000	74500	167500	3700	8
130 to 135	18	24	64	145	31900	54100	—	86000	84600	170600	4000	8
136-137	18	24	64	145	31375	50475	—	81850	84600	166450	4000	8
138 to 143	18	24	64	145	34000	60000	—	94000	74500	168500	3700	8
144-145	18	24	63	145	34000	61000	—	95000	74000	169000	3700	7
146-147	18½	26	62	140	36000	72000	—	108000	61000	169000	3000	8
148 to 151	18	24	64	155	33700	62000	—	95700	72300	168000	4000	8
152 to 154	18	24	64	150	35000	54200	—	89200	80600	169800	4000	8
155	17	24	59	140	33200	54400	—	87600	75600	163200	3800	8
156	17	24	59	150	29000	49000	—	78000	70000	148000	4000	8
157	17	24	64	150	28000	52000	—	80000	80000	160000	4000	8
158	18	24	64	160	39000	64000	—	103000	87000	190000	3500	10
160	18	24	62	160	38900	64000	—	102900	87000	189900	3500	10
161	18	24	62	140	39600	63300	—	102400	73000	175900	3100	8
162	18	26	64	140	39600	64000	—	103600	74800	177600	2800	8
182 to 187	18	26	69	180	41000	84000	—	125000	90000	215000	4300	8
188-189	18	26	69	180	41800	81800	—	123600	90200	213800	4000	8

TABLE VI – SHEET 3 – FRISCO ROAD LOCOMOTIVES.

ENGINE #	DIAM. CYL. INCHES	STROKE INCHES	DIAM. DRIVER INCHES	BOILER PRESSURE	WEIGHT ON TRUCK	WEIGHT ON DRIVERS	WEIGHT ON TRAILER	TOTAL WT ENGINE	TOTAL WT TENDER	TOTAL WT ENGINE AND TENDER	WATER CAP. GAL.	COAL TONS
190 TO 195	18	26	69	200	45200	88600	—	133800	107200	241000	4500	10
200 TO 204	19	26	69	200	44000	90000	—	134000	91700	225700	4300	10
205 TO 219	19	26	69	200	43700	100000	—	143700	108200	251900	4000	8
220 TO 229	19	26	69	200	46700	96700	—	143400	105300	248700	4000	10
300 TO 303	19	24	56½	150	17600	83375	—	100975	72300	173275	4000	8
304 TO 316	19	24	56½	145	15900	76800	—	92700	84600	177300	3900	8
317 TO 336	19	24	56½	145	15400	81600	—	97000	84600	181600	4000	8
337 TO 353	19	24	56½	155	24400	81900	—	106300	84600	190900	4000	8
354 TO 358	19	24	55	155	16000	96000	—	112000	84000	196000	4000	10
359 - 360	18	24	55	180	18000	99900	—	117900	91000	208900	4000	10
361 - 362	19	24	55	180	19000	106500	—	125500	92600	218100	4000	10
363 - 364	19	24	55	180	16000	102000	—	118000	87000	205000	4000	10
400-402 TO 404	19	24	56½	135	25800	60600	—	86400	76700	163100	4000	8
401-405-406	18	24	56½	135	25800	60600	—	86400	76700	163100	4000	8
407-408-409	19	24	56½	145	25800	60600	—	86400	76700	163100	4000	8
410-411 413 TO 415	19	24	56½	140	23250	71900	—	95150	84600	179750	4000	8
416	19	24	56½	145	24900	68950	—	93850	84600	178450	4000	8
417 TO 421	19	24	56½	145	24000	67100	—	91100	84600	175700	4000	10
426-427	19	24	56½	145	24000	67100	—	91100	84600	175700	4000	8
428 TO 437	19	24	59	145	27500	69500	—	97000	84600	181600	4000	8
438 TO 447	19	24	64	165	24700	107500	—	132200	86800	219000	4000	8

Engine #	Diam Cyl. Inches	Stroke Inches	Diam. Driver Inches	Boiler Pressure	Weight On Truck	Weight On Drivers	Weight On Trailer	Total Wt. Engine	Total Wt. Tender	Total Wt. Engine And Tender	Water Cap.-Gal.	Coal Tons.
448 To 458	19	24	57	150	25400	91000	——	116400	71000	187400	4000	8
459 To 466	19	24	57	160	25400	91000	——	116400	71000	187400	4000	8
487 To 490	19	26	63	160	27000	103000	——	130000	77100	207100	4200	8
491 To 500	19	26	57	155	22000	99000	——	121000	74100	195100	3800	8
501 To 504 506 To 515	19	26	57	160	22000	99000	——	121000	77100	198100	3800	8
516 To 520	20½	26	63	200	44350	129200	——	173550	134000	307550	6000	12
521 To 530	20½	26	63	200	44350	129200	——	173550	116600	290150	5000	11
539 To 548	20	24	64	180	34800	113600	——	148400	92000	240400	5000	10
549 To 557	20	26	63	200	29600	120000	——	149600	111300	260900	5000	12
558 To 567	20	26	63	190	34000	126000	——	160000	130000	290000	6000	14
568 To 572	20	26	63	190	27100	123700	——	150800	120600	271400	6000	12
573 - 574	20	26	63	180	27350	131000	——	158350	109200	267550	5000	10
575 To 584	20	26	57	200	27000	126000	——	153000	91732	244732	4300	10
585 To 594	20	26	63	200	34500	126700	——	161200	109250	270450	5000	10
595 To 599	20	26	63	200	35000	124800	——	159800	109200	269000	5000	10
600 To 604	20	28	69	190	36000	125400	——	161400	111300	272700	5000	12
605 To 609	20	28	69	190	37200	130500	——	167700	111300	279000	5000	12
610 To 619	20½	26	63	200	43100	129700	——	172800	116600	289400	5000	11
620 To 623	20½	26	63	200	42350	131200	——	173550	134000	307550	6000	12
624 To 628	21	26	69	200	42100	130700	——	172800	134000	306800	6000	12
629 To 633	21	26	69	200	44750	137750	——	182500	132800	315300	6000	14
634 To 668	20½	26	63	200	42350	131200	——	173550	134000	307550	6000	12

TABLE VI - SHEET 5 - FRISCO ROAD LOCOMOTIVES

ENGINE #	DIAM. CYL. INCHES	STROKE INCHES	DIAM. DRIVER INCHES	BOILER PRESSURE	WEIGHT ON TRUCK	WEIGHT ON DRIVERS	WEIGHT ON TRAILER	TOTAL WT. ENGINE	TOTAL WT. TENDER	TOTAL WT. ENGINE AND TENDER	WATER CAP.-GAL.	COAL TONS.
669 TO 693	20	26	63	200	35000	124800	——	159800	109200	269000	5000	10
695 TO 699	21	28	63	200	55300	142600	——	197900	132800	330700	6000	14
700 TO 704	H.P. 22 L.P. 35	26	63	200	38400	125900	——	164300	109200	273500	5000	10
705 TO 724	21	28	63	200	55300	142600	——	197900	132800	330700	6000	14
727 TO 741	21	28	63	200	46500	139350	——	185850	132800	318650	6000	14
743 TO 746, 748, 752, 753, 754, 756 TO 759, 763 TO 770, 772, 773, 774.	H.P. 15½ L.P. 26	28	63	200	51100	138300	——	189400	133400	322800	6000	14
742, 747, 749, 750, 751, 755, 760, 761, 762, 771, 775 TO 799	21	28	63	200	49600	138700	——	188300	133400	321700	6000	14
801 TO 818	21	28	57	185	16000	142000	——	158000	111300	2693[redacted]	5000	12
819 TO 828	21	28	57	200	16100	145200	——	161300	111300	272600	5000	12
829 TO 833	21	28	57	200	17100	143200	——	160300	111300	271600	5000	12
834 - 835	20	28	51	200	19000	145000	——	164000	125800	289800	6000	13
950 TO 955	21	28	55	190	17000	154000	——	171000	105000	276000	5000	10
956 TO 965	21	28	57	200	19000	155500	——	174500	113800	283300	6000	14
970 TO 989	21	28	55	200	21450	160050	——	181500	128300	309800	6000	12
1000 TO 1009	20	26	69	200	39100	123400	31050	193550	134250	327800	6000	13
1010 TO 1014	20	26	69	200	38200	118800	34000	191000	139500	330500	6000	13
1015 TO 1039	26	28	69	160	44000	145500	36000	225500	151800	377300	8100	11½
1100 TO 1111	21	26	69	200	48000	139000	——	187000	131700	318700	6000	12
1200 TO 1225	22	30	57	200	20000	178000	——	198000	148400	346400	7500	12
1226 TO 1265	22	30	57	200	20000	187000	——	207000	148400	355400	7500	12

Table VI - Sheet 6 Frisco Road Locomotives.

Engine #	Diam. Cyl. Inches	Stroke Inches	Diam. Driver Inches	Boiler Pressure	Weight On Truck	Weight On Drivers	Weight On Trailer	Total Wt. Engine	Total Wt. Tender	Total Wt. Engine and Tender	Water Cap.-Gal.	Coal Tons
1266 to 1280	23	30	63	200	20650	195050	——	215700	143600	359300	7500	12
1281 to 1292	26	30	63	165	26100	201100	——	227200	149700	476900	7500	12
1293 to 1305	26	30	63	165	24800	196200	——	221000	147000	368000	7500	12
1400 to 1409	23	26	69	200	53000	143000	——	196000	135300	331300	6000	14
2001 to 2007	HP 24½ LP 39	30	57	200	25500	360000	32500	418000	161300	579300	8000	16
2232 to 2235	16	24	66	150	30700	51300	——	82000	65000	147000	3200	7
2236 - 2237	16	24	64	150	30700	51300	——	82000	65000	147000	3200	7
2241	16	24	59	130	26000	47000	——	73000	67000	140000	3200	7
2252	17	24	63	130	28000	52000	——	80000	50000	130000	2600	7
2253	17	24	63	120	28000	52000	——	80000	50000	130000	2600	7
2255	17	24	63	120	28000	52000	——	80000	50000	130000	2600	7
2260	17	24	63	135	28000	52000	——	80000	50000	130000	2600	7
2263	17	24	59	135	28000	52000	——	80000	50000	130000	2600	7
2264	17	24	64	140	28000	52000	——	80000	55000	135000	3000	7
2266	18	24	63	135	28000	56000	——	84000	54000	138000	2500	7
2267	17	24	61	135	28000	52000	——	80000	50000	130000	2500	7
2274	17	24	63	135	27300	57700	——	85000	73800	158800	3000	8
2275	16	24	63	135	27300	50400	——	77700	61300	139000	2800	8
2650 to 2652	18	24	53	140	27100	69200	——	96300	84600	180900	4000	8
2653	19	24	56½	135	25800	60600	——	86400	84600	171700	4000	8
2654	18	24	56½	135	28000	66000	——	94000	84600	178600	4000	8
2657 - 2658	18	24	56½	135	24000	56000	——	80000	84600	164600	4000	8

TABLE VI – SHEET 7. FRISCO ROAD LOCOMOTIVES.

ENGINE #	DIAM. CYL. INCHES	STROKE INCHES	DIAM. DRIVER INCHES	BOILER PRESSURE	WEIGHT ON TRUCK	WEIGHT ON DRIVERS	WEIGHT ON TRAILER	TOTAL WT. ENGINE	TOTAL WT. TENDER	TOTAL WT. ENGINE AND TENDER	WATER CAP. GAL.	COAL TONS.
2659 TO 2666	18	24	55	140	30500	67500	———	98000	84600	182600	4000	8
2667 - 2668	18	24	53	140	27100	69200	———	96300	84600	180900	4000	8
2669	18	24	56½	135	29400	63000	———	92400	84500	176900	4000	8
2670 TO 2675	18	24	53	140	25000	67600	———	92600	84600	177200	3700	6
2676 TO 2691	18	24	55	145	20200	86200	———	106400	84600	191000	4000	8
2692 TO 2695	18	24	53	150	26300	76900	———	103200	84600	187800	4000	8
2698	18	24	63	180	33000	94800	———	127800	87000	214800	5000	10
2700 TO 2715	20	24	51	145	15100	93100	———	108200	84600	192800	4000	8
2716 TO 2719	20	24	51	145	14500	89500	———	104000	84600	188600	4000	8
2720 TO 2723	20	24	51	145	15000	95100	———	100100	84600	184700	4000	8
2724 TO 2730	20	24	51	155	13900	100200	———	114100	84600	198700	4000	8
2731 TO 2733	20	24	51	160	13400	104900	———	118300	84600	202900	4000	8
2735	20	24	51	125	15000	87000	———	102000	72300	174300	3200	8
2737	20	24	51	135	15000	87000	———	102000	72300	174300	3200	8

of all Frisco road locomotives, also sufficient additional information concerning each engine so that the tractive effort may be calculated.

The figures so far derived show only the available tractive effort at the circumference of the drivers, and takes no account of the friction of the moving parts of the locomotive, the resistance due to the weight of the locomotive itself, the air resistance or the grade resistance. To be useful for rating purposes it is not the tractive effort at the drivers which is desired but the tractive effort back of the tender, or as commonly expressed, "the draw bar pull", To obtain the draw bar pull at any given speed all these other resistances must be deducted from the tractive effort at the circumference of the drivers. The resistances to be taken into account may be summarized as follows:-

1.-Resistance due to internal friction in engine, and including rolling and journal friction, friction in pin bearings, stuffing box, cylinder, valves and link motion.

2.-Rolling resistance in trucks and trailers.

3.-Resistance to uniform motion in tender.

4.-Head air resistance.

5.-Grade resistance.

To the above list curve resistance is sometimes added, but as stated previously, it is considered better to add the curve resistance to the grade resistance, and consider it merely as so much additional grade.

The total energy to be expended in overcoming the internal friction will depend on a great many factors, such as the composition of the bearings, and the condition of the surfaces in contact, as well as the lubricant used and the manner in which it is applied. The stuffing box packing if not properly tightened may greatly reduce the power transmitted to the drivers. The size of the bearings, and the pressure per square inch allowed on the same, the accuracy of the counterbalancing and the per cent of lost motion all play an important part in the total internal friction.

Much investigation has been made by mechanical engineers and superintendents in view of deriving some relation between internal friction and tractive effort. The results have varied as greatly as those for train resistance. The lowest estimate indicates a consumptionof two per cent of theoretical tractive effort and the highest indicates ten per cent. It is evident that the friction should not be greatly different at high and low speeds, because the parts are principally reciprocating and not rotating, so that there is very little centrifugal motion in the parts of the engine itself to be overcome, outside of the rotation of the wheels. The experiments made have shown that about one-third of the total internal friction is in the driving wheel boxes, which is naturally to be expected as they receive the full thrust of the piston, as well as the weight of the engine. Some account should evidently be taken of the weight on the drivers then. As the weight on the drivers increases, the total friction in the valves, side-rod bearings, cross-head, etc., also increases as they must be made to correspond in size to the size of the engine, which conversely is proportioned according to the desired driving wheel load. This makes it more desirable to express the internal friction in terms of the weight on the drivers. It has been commonly accepted that the internal friction expressed in such terms is practically uniform at 22.2 lbs. per ton of weight on the drivers. This figure in reality is the figure derived by the American Locomotive Company, but it has commonly been accepted, and agrees very well with labratory tests made by different roads.

Prof. Goss once presented to the New York Railroad Club the following formula for internal friction:-

$$\frac{3.8\ d^2 s}{D}, \text{ where}$$

d = diameter of cylinder ininches.
s = stroke of piston in inches.
D = diameter of drivers in inches.

The formula derived by Mr. Geo. R. Henderson and presented in his work entitled "Locomotive Operation" is as follows:-

$$.15\ V + c, \quad \text{where}$$

V = speed in miles per hour.
c = a constant varying from 2 to 8, the latter to be used in the case of heavy slow work.

Mr. Henderson's formula is one of a very few which consider the train speed. From these different formulae the internal friction in say Frisco engine #801, dimensions of which are given in table VI, would be as follows at ten miles per hour:-

By Prof. Goss:-

$$3.8\ \frac{21^2 \times 28}{57} = 823\#$$

By Geo. R. Henderson:-

.15 x 10 + 8 = 9.5% of Indicated Tractive Effort of cylinders or 9.5% of 34070# = 3236#.

By weight on drivers:-

71 x 22.2# = 1576#

At 20 miles per hour the internal friction as figured from the Henderson formula would be,

.15 x 20 + 8 = 11% of 24870# = 2735#

The experiments of Prof. Goss were made at the Purdue University testing laboratory, and were stated to have been made on an engine with 17" cylinder, 24" stroke and 63" driving wheel. The same specifications would fit Frisco engine #53 for example. Internal friction by the Goss formula, for this engine, would be 420#, and from the weight on the drivers 600#, which shows that the Goss formula does not consider the internal resistance as depending on the weight on the drivers, or as being in any proportion or ratio to such weight. In discussing the resistance of cars it was found that at ten miles per hour the resistance of say a 15 ton car per ton of weight was 8.2 pounds, while the resistance per ton of a 75 ton car at the same speed was only 3.2 pounds. From this it is evident that the weight of an engine on its drivers must make a difference in the resistance per ton. For this same reason it is evident that 22.2 pounds per ton will not be a correct expression of internal resistance for all engines, or all speeds, although the speed probably plays less part in changing the resistance than the weight. However, while the journal friction decreases materially as the weight on the drivers increases, the other internal friction resistances, comprising about tho thirds of the total, increase per ton owing to the heavy increase in size of piston, valves and connections. It is for this reason that the total friction is usually considered as uniform per ton of weight on different engines. In well designed locomotives there is a direct relation between the size of driving pins, valves, cylinders, journals, etc. and the weight on the drivers, which in the end is the criterion of tha maximum tractive effort which the engine is capable of producing.

The figure of 22.2 pounds per ton, accepted by the American Locomotive Comapny, will be accepted here with the explanations given. It is believed in light of recent experiments that the resistance is very nearly uniform at different speeds, owing to the mechanics of the engine, but there is considerable doubt as to whether the resistance is the same for different weights of engines, any more than it is for different weights of cars. Experience has shown, however, that the resistance ordinarily becomes less per ton as the weight per ton on the journals increases. As the head air resistance is considered separately, we would not expect anything like the variation shown in the different weight cars.

As a whole the question of internal engine resistance seems to have been very unsatisfactorily settled among mechanical men. The problem is somewhat analagous to the question of train resistance, for which so may formulae have been derived. Individuality in locomotive design is a large factor in preventing a universal resistance formula from being derived, so that the only safe recourse is to use an average figure with a factor of safety. No machine will show the same internal friction when new and when the bearings have worm smooth and fit each other perfectly, and this is perhaps better illustrated in locomotives than anywhere else. After coming from the shop an engine is ordinarily run about one hundred miles before being placed in road service. This is in order to get all the parts well adjusted and especially to let the new bearings wear down a little before a heavy load is placed upon them. For several trips the engine will probably heat more or less in the bearings, which shows conclusively that there is a large amount of friction being transformed into heat. Even after running thousands of miles we would not expect two engines exactly alike in every respect to show the same total internal friction. Our allowance for friction should be such, them, that it will be the ordinary maximum for engines which may be considered as thoroughly broken in, and it is believed the figure adopted will satisfy these conditions.

The rolling and other resistances in trucks, trailer and tender, may be taken as the same as in cars of equal weight, each being considered separately.

The head air resistance may be calculated with considerable accuracy by applying the theories and rules of hydraulics. The results agree fairly well with the records of experiments.

In the development of a formula expressing head air resistance we may start with the hydraulic formula--

$v = \sqrt{2gh}$, where

v = velocity in feet per second.
g = acceleration of gravity = 32.2 feet, per sec.
h = head in feet.

For h may be substituted P/w, where P = the pressure in pounds per square foot of surface and w = weight of one cubic foot of air, which is .076 pounds. The equation will then read:-

$$v = \sqrt{2g\ P/w}$$

or $v^2 = 2g\ P/w$, from which

$$P = \frac{v^2 w}{2g} \quad \text{or } P = \frac{v^2 \times .076}{2 \times 32.2}$$

If V = velocity in miles per hour we may substitute for v, the following,

$$v = V \times \frac{5280}{3600} = V\ 1.467 \quad \text{or}$$

$$v^2 = 2.15\ V^2$$

Now substituting in the equation expressing P, we obtain,

$$P = \frac{2.15\ V^2 \times .076}{2 \times 32.2} = .0025\ V^2$$

which is the expression of head air resistance per square foot of resisting surface.

Many of the formulae which have been derived to express train resistance include the head air resistance derived as above, but reduced to pounds per ton on the basis of an arbitrary weight per car and head end area. A glance at the list of formulae presented under discussion of train resistance shows that practically every formula contains the expression as the last term, the variation in the constant expressing the authors opinion as to what constituted an average weight per car and head end area. If an engine is driving straight into a thirty mile wind at thirty miles per hour, it is evident the head air resistance will be the same as if the engine was running sixty miles per hour into no wind. For this reason it is sometimes necessary to reduce tonnage on account of high winds, as the available tractive power is reduced in overcoming the head air resistance. On the other hand if an engine is running with the wind the head air resistance will be decreased in proportion.

Each engine has a different head end area, owing to the general proportions of the engine, but it is customary to assume a 10' by 12' surface or 120 square feet. This is sufficiently close for practical purposes. For example, the head air resistance at thirty miles per hour for 120 square feet would be 270 pounds, and for a 10' x 14' area or 140 square feet surface would be 315 pounds, or only 45 pounds greater. The largest Frisco engines have very nearly 120 square feet head end area, and the smallest about 100 square feet. Hence, if we assume a uniform area of 120 square feet there will be only a small error introduced into available tractive effort at draw bar, less than one-tenth of one per cent at ordinary speed, for the maximum error in head end area.

Accepting 120 square feet as the average head end area we may write the empirical equation for head air resistance, expressed in pounds, as--

$$p = 120 \times .0025 V^2 = .3 V^2$$

The head air resistance would be as follows for various speeds, derived from above formula:--

M.P.H.	Head Air Resistance-Pounds--
10	30
15	68
20	120
25	198
30	270
35	368
40	480
45	608
50	750
55	908
60	1080

The fifth item to be subtracted from tractive effort by the cylinders to obtain draw bar pull is the resistance due to grade. This resistance as seen later is 20 pounds per ton multiplied by the rate per cent of grade, or as commonly written, 20Rg.

If we let x = resistance in truck, x_1=resistance in trailer, x_2= resistance in tender with full supply of coal and water, T = weight in tons on drivers and W = total weight of engine and loaded tender, we may write the following expression for the theoretical draw bar pull of any simple engine on any grade at any speed.

$$D.B.P. = \frac{d^2 s\ KF\ 85}{D} - (x + x_1 + x_2 + 22.2\ T + .3V^2 + 20RgW)$$

The first term of the equation it will be remembered expresses indicated tractive effort of cylinders. In case the tractive effort by adhesion is less than the tractive effort by the cylinders at the circumference of the drivers, which would be found by subtracting the internal friction from the theoretical tractive effort of the cylinders, there should be substituted for the first term of the equation one quarter of the weight on the drivers, and the term expressing internal friction should be dropped. Or it may be stated the draw bar pull in such cases will be limited to the tractive effort by adhesion less the resistance in pony trucks, trailers, tender and head air resistance.

To find the draw bar pull of a two cylinder or four cylinder compound, we may substitute for the first term the equation of indicated tractive effort by the cylinders for either class of compound engine for which the draw bar pull is required. The equation for two cylinder compound will then be expressed:--

$$D.B.P. = \left(\frac{C^2 s\ R\ P}{2D} + \frac{c^2 s\ R_1\ P}{2D}\right) - (x + x_1 + x_2 + 22.2\ T + .3V^2 + 20\ Rg\ W)$$

The equation for four cylinder compounds will be expressed:

$$D.B.P. = \left(\frac{C^2 sRP}{D} + \frac{C^2 sR_1 P}{D}\right) - (x + x_1 + x_2 + 22.2\ T + .3V^2 + 20\ Rg\ W)$$

There is given as Table VII the draw bar pull of all Frisco road locomotives for speeds between 10 miles per hour and 60 miles per hour and on grades up to two per cent. The speeds are selected at 5 miles per hour intervals and for all practical purposes the draw bar pull for speeds between limits given may be obtained by interpolation. The grades are given for each .1 foot up to two per cent grade and interpolation may be accurately used for grades between limits given.

By means of tables VII and I there may be readily computed the total tonnage of cars of any given average weight which may be hauled by any Frisco road locomotive on any grade at any speed between 10 and 60 miles per hour. This may be expressed as a formula as follows:-

$$T = \frac{D.B.P.}{R + Rg}, \text{ where}$$

T = Total weight of train in tons back of tender.
DBP = Draw bar pull selected from table VIII.
R = Train resistance per ton for average weight of cars in train.
Rg = Resistance due to grade, and equal to 20 lbs. per ton for each 1.00% of grade (for cars only, as deduction is already made in engine)

For example, let it be desired to rate engine 1200 for cars of 35 ton average weight on a ruling grade of 1.00%, and for a speed of ten miles per hour. Then,

$$T = \frac{34828}{5.2 + 20} = 1382 \text{ Tons.}$$

ENGINE No. 26-27

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	11281	10766	9486	8205	6924	5606	4585	3726	2950	2260	1610
0.1	11087	10572	9292	8011	6730	5412	4391	3532	2756	2066	1416
0.2	10893	10378	9098	7817	6536	5218	4197	3338	2562	1872	1222
0.3	10699	10184	8904	7623	6342	5024	4003	3144	2368	1678	1028
0.4	10505	9990	8710	7429	6148	4830	3809	2950	2174	1484	834
0.5	10311	9796	8516	7235	5954	4636	3615	2756	1980	1290	640
0.6	10117	9602	8322	7041	5760	4442	3421	2562	1786	1096	446
0.7	9923	9408	8128	6847	5566	4248	3227	2368	1592	902	252
0.8	9729	9214	7934	6653	5372	4054	3033	2174	1398	708	58
0.9	9535	9020	7740	6459	5178	3860	2839	1980	1204	514	
1.0	9341	8826	7546	6265	4984	3666	2645	1786	1010	320	
1.1	9147	8632	7352	6071	4790	3472	2451	1592	816	126	
1.2	8953	8438	7158	5877	4596	3278	2257	1398	622		
1.3	8759	8244	6964	5683	4402	3084	2063	1204	428		
1.4	8565	8050	6770	5489	4208	2890	1869	1010	234		
1.5	8371	7856	6576	5295	4014	2696	1675	816	40		
1.6	8177	7662	6382	5101	3820	2502	1481	622			
1.7	7983	7468	6188	4907	3626	2308	1287	428			
1.8	7789	7274	5994	4713	3432	2114	1093	234			
1.9	7595	7080	5800	4519	3238	1920	899	40			
2.0	7401	6886	5606	4325	3044	1726	705				

ENGINE No. 69.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
	10	15	20	25	30	35	40	45	50	55	60
0.0	11031	10965	9946	8445	6954	5606	4605	3706	2930	2210	1560
0.1	10837	10771	9752	8251	6760	5412	4411	3512	2736	2016	1366
0.2	10643	10577	9558	8057	6566	5218	4217	3318	2542	1822	1172
0.3	10449	10383	9364	7863	6372	5024	4023	3124	2348	1628	978
0.4	10255	10189	9170	7669	6178	4830	3829	2930	2154	1434	784
0.5	10061	9995	8976	7475	5984	4636	3635	2736	1960	1240	590
0.6	9867	9801	8782	7281	5790	4442	3441	2542	1766	1046	396
0.7	9673	9607	8588	7087	5596	4248	3247	2348	1572	852	202
0.8	9479	9413	8394	6893	5402	4054	3053	2154	1378	658	8
0.9	9285	9219	8200	6699	5208	3860	2859	1960	1184	464	
1.0	9091	9025	8006	6505	5014	3666	2665	1766	990	270	
1.1	8897	8831	7812	6311	4820	3472	2471	1572	796	76	
1.2	8703	8637	7618	6117	4626	3278	2277	1378	602		
1.3	8509	8443	7424	5923	4432	3084	2083	1184	408		
1.4	8315	8249	7230	5729	4238	2890	1889	990	214		
1.5	8121	8055	7036	5535	4044	2696	1695	796	20		
1.6	7927	7861	6842	5341	3850	2502	1501	602			
1.7	7733	7667	6648	5147	3656	2308	1307	408			
1.8	7539	7473	6454	4953	3462	2114	1113	214			
1.9	7345	7279	6260	4759	3268	1920	919	20			
[illegible]	7151	1085	6066	4565	3074	1726	725				

ENGINE No. — 31.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL. 10	15	20	25	30	35	40	45	50	55	60
0.0	11130	10758	9476	8195	6907	5592	4571	3710	2932	2240	1588
0.1	10930	10558	9276	7995	6707	5392	4371	3510	2732	2040	1388
0.2	10730	10358	9076	7795	6507	5192	4171	3310	2532	1840	1188
0.3	10530	10158	8876	7595	6307	4992	3971	3110	2332	1640	988
0.4	10330	9958	8676	7395	6107	4792	3771	2910	2132	1440	788
0.5	10130	9758	8476	7195	5907	4592	3571	2710	1932	1240	588
0.6	9930	9558	8276	6995	5707	4392	3371	2510	1732	1040	388
0.7	9730	9358	8076	6795	5507	4192	3171	2310	1532	840	188
0.8	9530	9158	7876	6595	5307	3992	2971	2110	1332	640	
0.9	9330	8958	7676	6395	5107	3792	2771	1910	1132	440	
1.0	9130	8758	7476	6195	4907	3592	2571	1710	932	240	
1.1	8930	8558	7276	5995	4707	3392	2371	1510	732	40	
1.2	8730	8358	7076	5795	4507	3192	2171	1310	532		
1.3	8530	8158	6876	5595	4307	2992	1971	1110	332		
1.4	8330	7958	6676	5395	4107	2792	1771	910	132		
1.5	8130	7758	6476	5195	3907	2592	1571	710			
1.6	7930	7558	6276	4995	3707	2392	1371	510			
1.7	7730	7358	6076	4795	3507	2192	1171	310			
1.8	7530	7158	5876	4595	3307	1992	971	110			
1.9	7330	6958	5676	4395	3107	1792	771				
2.0	7130	6758	5476	4195	2907	1592	571				

TABLE VII Showing Draw Bar Pull of Frisco Locomotives

SHEET 4.

ENGINE No. 32 AND 33, 38 AND 40.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL. 10	15	20	25	30	35	40	45	50	55	60
0.0	11031	10776	9496	8215	6934	5616	4595	3736	2960	2270	1620
0.1	10837	10582	9302	8021	6740	5422	4401	3542	2766	2076	1426
0.2	10643	10388	9108	7827	6546	5228	4207	3348	2572	1882	1232
0.3	10449	10194	8914	7633	6352	5034	4013	3154	2378	1688	1038
0.4	10255	10000	8720	7439	6158	4840	3819	2960	2184	1494	844
0.5	10061	9806	8526	7245	5964	4646	3625	2766	1990	1300	650
0.6	9867	9612	8332	7051	5770	4452	3431	2572	1796	1106	456
0.7	9673	9418	8138	6857	5576	4258	3237	2378	1602	912	262
0.8	9479	9224	7944	6663	5382	4064	3043	2184	1408	718	68
0.9	9285	9030	7750	6469	5188	3870	2849	1990	1214	524	
1.0	9091	8836	7556	6275	4994	3676	2655	1796	1020	330	
1.1	8897	8642	7362	6081	4800	3482	2461	1602	826	136	
1.2	8703	8448	7168	5887	4606	3288	2267	1408	632		
1.3	8509	8254	6974	5693	4412	3094	2073	1214	438		
1.4	8315	8060	6780	5499	4218	2900	1879	1020	244		
1.5	8121	7866	6586	5305	4024	2706	1685	826	50		
1.6	7927	7672	6392	5111	3830	2512	1491	632			
1.7	7733	7478	6198	4917	3636	2318	1297	438			
1.8	7539	7284	6004	4723	3442	2124	1103	244			
1.9	7345	7090	5810	4529	3248	1930	909	50			
2.0	7151	6896	5616	4335	3054	1736	715				

ENGINE No. - 34.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
	10	15	20	25	30	35	40	45	50	55	60
0.0	11006	10765	9483	8202	6914	5599	4578	3717	2939	2247	1595
0.1	10808	10567	9285	8004	6716	5401	4380	3519	2741	2049	1397
0.2	10610	10369	9087	7806	6518	5203	4182	3321	2543	1851	1199
0.3	10412	10171	8889	7608	6320	5005	3984	3123	2345	1653	1001
0.4	10214	9973	8691	7410	6122	4807	3786	2925	2147	1455	803
0.5	10016	9775	8493	7212	5924	4609	3588	2727	1949	1257	605
0.6	9818	9577	8295	7014	5726	4411	3390	2529	1751	1059	407
0.7	9620	9379	8097	6816	5528	4213	3192	2331	1553	861	209
0.8	9422	9181	7899	6618	5330	4015	2994	2133	1355	663	11
0.9	9224	8983	7701	6420	5132	3817	2796	1935	1157	465	
1.0	9026	8785	7503	6222	4934	3619	2598	1737	959	267	
1.1	8828	8587	7305	6024	4736	3421	2400	1539	761	69	
1.2	8630	8389	7107	5826	4538	3223	2202	1341	563		
1.3	8432	8191	6909	5628	4340	3025	2004	1143	365		
1.4	8234	7993	6711	5430	4142	2827	1806	945	167		
1.5	8036	7795	6513	5232	3944	2629	1608	747			
1.6	7838	7597	6315	5034	3746	2431	1410	549			
1.7	7640	7399	6117	4836	3548	2233	1212	351			
1.8	7442	7201	5919	4638	3350	2035	1014	153			
1.9	7244	7003	5721	4440	3152	1837	816				
2.0	7046	6805	5523	4242	2954	1639	618				

TABLE VII Showing Draw Bar Pull of Frisco Locomotives

SHEET - 6.

ENGINE No. -35.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	11545	10743	9462	8181	6897	5580	4569	3699	2922	2231	1580
0.1	11345	10543	9262	7981	6697	5380	4369	3499	2722	2031	1380
0.2	11145	10343	9062	7781	6497	5180	4169	3299	2522	1831	1180
0.3	10945	10143	8862	7581	6297	4980	3969	3099	2322	1631	980
0.4	10745	9943	8662	7381	6097	4780	3769	2899	2122	1431	780
0.5	10545	9743	8462	7181	5897	4580	3569	2699	1922	1231	580
0.6	10345	9543	8262	6981	5697	4380	3369	2499	1722	1031	380
0.7	10145	9343	8062	6781	5497	4180	3169	2299	1522	831	180
0.8	9945	9143	7862	6581	5297	3980	2969	2099	1322	631	
0.9	9745	8943	7662	6381	5097	3780	2769	1899	1122	431	
1.0	9545	8743	7462	6181	4897	3580	2569	1699	922	231	
1.1	9345	8543	7262	5981	4697	3380	2369	1499	722	31	
1.2	9145	8343	7062	5781	4497	3180	2169	1299	522		
1.3	8945	8143	6862	5581	4297	2980	1969	1099	322		
1.4	8745	7943	6662	5381	4097	2780	1769	899	122		
1.5	8545	7743	6462	5181	3897	2580	1569	699			
1.6	8345	7543	6262	4981	3697	2380	1369	499			
1.7	8145	7343	6062	4781	3497	2180	1169	299			
1.8	7945	7143	5862	4581	3297	1980	969	99			
1.9	7745	6943	5662	4381	3097	1780	769				
2.0	7545	6743	5462	4181	2897	1580	569				

TABLE VII Showing Draw Bar Pull of Frisco Locomotives

SHEET-7.

ENGINE No. -43.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	11637	11383	9912	8411	6917	5570	4569	3669	2892	2171	1520
0.1	11437	11183	9712	8211	6717	5370	4369	3469	2692	1971	1320
0.2	11237	10983	9512	8011	6517	5170	4169	3269	2492	1771	1120
0.3	11037	10783	9312	7811	6317	4970	3969	3069	2292	1571	920
0.4	10837	10583	9112	7611	6117	4770	3769	2869	2092	1371	720
0.5	10637	10383	8912	7411	5917	4570	3569	2669	1892	1171	520
0.6	10437	10183	8712	7211	5717	4370	3369	2469	1692	971	320
0.7	10237	9983	8512	7011	5517	4170	3169	2269	1492	771	120
0.8	10037	9783	8312	6811	5317	3970	2969	2069	1292	571	
0.9	9837	9583	8112	6611	5117	3770	2769	1869	1092	371	
1.0	9637	9383	7912	6411	4917	3570	2569	1669	892	171	
1.1	9437	9183	7712	6211	4717	3370	2369	1469	692		
1.2	9237	8983	7512	6011	4517	3170	2169	1269	492		
1.3	9037	8783	7312	5811	4317	2970	1969	1069	292		
1.4	8837	8583	7112	5611	4117	2770	1769	869	92		
1.5	8637	8383	6912	5411	3917	2570	1569	669			
1.6	8437	8183	6712	5211	3717	2370	1369	469			
1.7	8237	7983	6512	5011	3517	2170	1169	269			
1.8	8037	7783	6312	4811	3317	1970	969	69			
1.9	7837	7583	6112	4611	3117	1770	769				
2.0	7637	7383	5912	4411	2917	1570	569				

ENGINE No. - 44.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	11973	11145	9806	8485	7152	5795	4724	3867	3052	2347	1675
0.1	11769	10941	9602	8281	6948	5591	4520	3663	2848	2143	1471
0.2	11565	10737	9398	8077	6744	5387	4316	3459	2644	1939	1267
0.3	11361	10533	9194	7873	6540	5183	4112	3255	2440	1735	1063
0.4	11157	10329	8990	7669	6336	4979	3908	3051	2236	1531	859
0.5	10953	10125	8786	7465	6132	4775	3704	2847	2032	1327	655
0.6	10749	9921	8582	7261	5928	4571	3500	2643	1828	1123	451
0.7	10545	9717	8378	7057	5724	4367	3296	2439	1624	919	247
0.8	10341	9513	8174	6853	5520	4163	3092	2235	1420	715	43
0.9	10137	9309	7970	6649	5316	3959	2888	2031	1216	511	
1.0	9933	9105	7766	6445	5112	3755	2684	1827	1012	307	
1.1	9729	8901	7562	6241	4908	3551	2480	1623	808	103	
1.2	9525	8697	7358	6037	4704	3347	2276	1419	604		
1.3	9321	8493	7154	5833	4500	3143	2072	1215	400		
1.4	9117	8289	6950	5629	4296	2939	1868	1011	196		
1.5	8913	8085	6746	5425	4092	2735	1664	807			
1.6	8709	7881	6542	5221	3888	2531	1460	603			
1.7	8505	7677	6338	5017	3684	2327	1256	399			
1.8	8301	7473	6134	4813	3480	2123	1052	195			
1.9	8097	7269	5930	4609	3276	1919	848				
2.0	7893	7065	5726	4405	3072	1715	644				

TABLE VII Showing Draw Bar Pull of Frisco Locomotives

SHEET 9

ENGINE No. 45-46-47.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	11984	11157	9819	8498	7165	5810	4739	3887	3067	2365	1694
0.1	11782	10955	9617	8296	6963	5608	4537	3685	2865	2163	1492
0.2	11580	10753	9415	8094	6761	5406	4335	3483	2663	1961	1290
0.3	11378	10551	9213	7892	6559	5204	4133	3281	2461	1759	1088
0.4	11176	10349	9011	7690	6357	5002	3931	3079	2259	1557	886
0.5	10974	10147	8809	7488	6155	4800	3729	2877	2057	1355	684
0.6	10772	9945	8607	7286	5953	4598	3527	2675	1855	1153	482
0.7	10570	9743	8405	7084	5751	4396	3325	2473	1653	951	280
0.8	10368	9541	8203	6882	5549	4194	3123	2271	1451	749	78
0.9	10166	9339	8001	6680	5347	3992	2921	2069	1249	547	
1.0	9964	9137	7799	6478	5145	3790	2719	1867	1047	345	
1.1	9762	8935	7597	6276	4943	3588	2517	1665	845	143	
1.2	9560	8733	7395	6074	4741	3386	2315	1463	643		
1.3	9358	8531	7193	5872	4539	3184	2113	1261	441		
1.4	9156	8329	6991	5670	4337	2982	1911	1059	239		
1.5	8954	8127	6789	5468	4135	2780	1709	857	37		
1.6	8752	7925	6587	5266	3933	2578	1507	655			
1.7	8550	7723	6385	5064	3731	2376	1305	453			
1.8	8348	7521	6183	4862	3529	2174	1103	251			
1.9	8146	7319	5981	4660	3327	1972	901	49			
2.0	7944	7117	5779	4458	3125	1770	699				

TABLE VII Showing Draw Bar Pull of Frisco Locomotives

SHEET - 10.

ENGINE No. 48 TO 52.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	12184	11296	9923	8564	7177	5802	5414	4586	3732	2863	1699
0.1	11988	11100	9727	8368	6981	5606	5218	4390	3536	2667	1503
0.2	11792	10904	9531	8172	6785	5410	5022	4194	3340	2471	1307
0.3	11596	10708	9335	7976	6589	5214	4826	3998	3144	2275	1111
0.4	11400	10512	9139	7780	6393	5018	4630	3802	2948	2079	915
0.5	11204	10316	8943	7584	6197	4822	4434	3606	2752	1883	719
0.6	11008	10120	8747	7388	6001	4626	4238	3410	2556	1687	523
0.7	10812	9924	8551	7192	5805	4430	4042	3214	2360	1491	327
0.8	10616	9728	8355	6996	5609	4234	3846	3018	2164	1295	131
0.9	10420	9532	8159	6800	5413	4038	3650	2822	1968	1099	
1.0	10224	9336	7963	6604	5217	3842	3454	2626	1772	903	
1.1	10028	9140	7767	6408	5021	3646	3258	2430	1576	707	
1.2	9832	8944	7571	6212	4825	3450	3062	2234	1380	511	
1.3	9636	8748	7375	6016	4629	3254	2866	2038	1184	315	
1.4	9440	8552	7179	5820	4433	3058	2670	1842	988	219	
1.5	9244	8356	6983	5624	4237	2862	2474	1646	792	23	
1.6	9048	8160	6787	5428	4041	2666	2278	1450	596		
1.7	8852	7964	6591	5232	3845	2470	2082	1254	400		
1.8	8656	7768	6395	5036	3649	2274	1886	1058	204		
1.9	8460	7572	6199	4840	3453	2078	1690	862			
2.0	8264	7376	6003	4644	3257	1882	1494	666			

ENGINE No.-53.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
	10	15	20	25	30	35	40	45	50	55	60
0.0	12608	11701	10273	8864	7442	6017	4946	4076	3218	2484	1804
0.1	12408	11501	10073	8664	7242	5817	4746	3876	3018	2284	1604
0.2	12208	11301	9873	8464	7042	5617	4546	3676	2818	2084	1404
0.3	12008	11101	9673	8264	6842	5417	4346	3476	2618	1884	1204
0.4	11808	10901	9473	8064	6642	5217	4146	3276	2418	1684	1004
0.5	11608	10701	9273	7864	6442	5017	3946	3076	2218	1484	804
0.6	11408	10501	9073	7664	6242	4817	3746	2876	2018	1284	604
0.7	11208	10301	8873	7464	6042	4617	3546	2676	1818	1084	404
0.8	11008	10101	8673	7264	5842	4417	3346	2476	1618	884	204
0.9	10808	9901	8473	7064	5642	4217	3146	2276	1418	684	4
1.0	10608	9701	8273	6864	5442	4017	2946	2076	1218	484	
1.1	10408	9501	8073	6664	5242	3817	2746	1876	1018	284	
1.2	10208	9301	7873	6464	5042	3617	2546	1676	818	84	
1.3	10008	9101	7673	6264	4842	3417	2346	1476	618		
1.4	9808	8901	7473	6064	4642	3217	2146	1276	418		
1.5	9608	8701	7273	5864	4442	3017	1946	1076	218		
1.6	9408	8501	7073	5664	4242	2817	1746	876	18		
1.7	9208	8301	6873	5464	4042	2617	1546	676			
1.8	9008	8101	6673	5264	3842	2417	1346	476			
1.9	8808	7901	6473	5064	3642	2217	1146	276			
2.0	8608	7701	6273	4864	3442	2017	946	76			

ENGINE No 54, 56 to 60, 62, 63, 65, 67, 68.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	12123	11108	9704	8304	6908	5527	4539	3658	2900	2160	1557
0.1	11943	10928	9524	8124	6728	5347	4359	3478	2720	1980	1377
0.2	11763	10748	9344	7944	6548	5167	4179	3298	2540	1800	1197
0.3	11583	10568	9164	7764	6368	4987	3999	3118	2360	1620	1017
0.4	11403	10388	8984	7584	6188	4807	3819	2938	2180	1440	837
0.5	11223	10208	8804	7404	6008	4627	3639	2758	2000	1260	657
0.6	11043	10028	8624	7224	5828	4447	3459	2578	1820	1080	477
0.7	10863	9848	8444	7044	5648	4267	3279	2398	1640	900	297
0.8	10683	9668	8264	6864	5468	4087	3099	2218	1460	720	117
0.9	10503	9488	8084	6684	5288	3907	2919	2038	1280	540	
1.0	10323	9308	7904	6504	5108	3727	2739	1858	1100	360	
1.1	10143	9128	7724	6324	4928	3547	2559	1678	920	180	
1.2	9963	8948	7544	6144	4748	3367	2379	1498	740		
1.3	9783	8768	7364	5964	4568	3187	2199	1318	560		
1.4	9603	8588	7184	5784	4388	3007	2019	1138	380		
1.5	9423	8408	7004	5604	4208	2827	1839	958	200		
1.6	9243	8228	6824	5424	4028	2647	1659	778	20		
1.7	9063	8048	6644	5244	3848	2467	1479	598			
1.8	8883	7868	6464	5064	3668	2287	1299	418			
1.9	8703	7688	6284	4884	3488	2107	1119	238			
2.0	8523	7508	6104	4704	3308	1927	939	58			

ENGINE No. 4

GRADE	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40	[illegible]	50	[illegible]	[illegible]
0.0	11709	[illegible]	[illegible]	8240	[illegible]	[illegible]	4534	[illegible]	[illegible]	2199	1570
[illegible]	[illegible]	[illegible]	9334	8064	6698	[illegible]	4354	[illegible]	[illegible]	2019	1890
[illegible]	11349	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3353	[illegible]	[illegible]	1210
0.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3944	[illegible]	[illegible]	[illegible]	1030
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1479	850
0.5	[illegible]	9958	[illegible]	[illegible]	[illegible]	4642	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4462	3454	[illegible]	831	1119	490
0.7	[illegible]	[illegible]	8254	[illegible]	5618	[illegible]	[illegible]	[illegible]	1651	939	310
[illegible]	[illegible]	9418	[illegible]	6804	5438	4102	3094	[illegible]	1471	759	130
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5258	[illegible]	[illegible]	[illegible]	1291	579	
[illegible]	9909	[illegible]	[illegible]	6444	[illegible]	3742	[illegible]	1913	1111	399	
[illegible]	[illegible]	8878	[illegible]	[illegible]	4898	3562	2554	[illegible]	[illegible]	[illegible]	
1.2	[illegible]	[illegible]	[illegible]	6084	[illegible]	[illegible]	2374	[illegible]	751	39	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1373	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	5774	[illegible]	3022	2014	[illegible]	391		
[illegible]	[illegible]	[illegible]	6814	[illegible]	4178	2842	1834	[illegible]	[illegible]		
1.6	8829	[illegible]	[illegible]	[illegible]	3998	2662	1654	[illegible]	31		
[illegible]	[illegible]	[illegible]	[illegible]	5184	3818	[illegible]	[illegible]	653			
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2302	[illegible]	[illegible]			
[illegible]	8289	7438	[illegible]	4824	3458	[illegible]	[illegible]	[illegible]			
[illegible]	[illegible]	[illegible]	5914	[illegible]	3278	1942	934	[illegible]			

TABLE VII. Showing Draw Bar Pull of Frisco Locomotives. SHEET 14.

ENGINE No. 69, 70, 72, 73, 74.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL. 10	15	20	25	30	35	40	45	50	55	60
0.0	11512	10718	9434	8154	6878	5562	4539	3683	2919	2206	1587
0.1	11332	10538	9254	7974	6698	5382	4359	3503	2739	2026	1407
0.2	11152	10358	9074	7794	6518	5202	4179	3323	2559	1846	1227
0.3	10972	10178	8894	7614	6338	5022	3999	3143	2379	1666	1047
0.4	10792	9998	8714	7434	6158	4842	3819	2963	2199	1486	867
0.5	10612	9818	8534	7254	5978	4662	3639	2783	2019	1306	687
0.6	10432	9638	8354	7074	5798	4482	3459	2603	1839	1126	507
0.7	10252	9458	8174	6894	5618	4302	3279	2423	1659	946	327
0.8	10072	9278	7994	6714	5438	4122	3099	2243	1479	766	147
0.9	9892	9098	7814	6534	5258	3942	2919	2063	1299	586	
1.0	9712	8918	7634	6354	5078	3762	2739	1883	1119	406	
1.1	9532	8738	7454	6174	4898	3582	2559	1703	939	226	
1.2	9352	8558	7274	5994	4718	3402	2479	1523	759	46	
1.3	9172	8378	7094	5814	4538	3222	2199	1343	579		
1.4	8992	8198	6914	5634	4358	3042	2019	1163	399		
1.5	8812	8018	6734	5454	4178	[illegible]	1839	983	219		
1.6	8632	7838	6554	5274	3998	[illegible]	1659	803	39		
1.7	8452	7658	6374	5094	3818	[illegible]	1479	623			
1.8	8272	7478	6194	4914	3638	[illegible]	1299	443			
1.9	8092	7298	6014	4734	3458	[illegible]	1119	263			
2.0	7912	7118	5834	4554	3278	[illegible]	939	83			

ENGINE No. -75-78 TO 90.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	11709	10858	9514	8244	6878	5542	4534	3713	2911	2199	1570
0.1	11529	10678	9334	8064	6698	5362	4354	3533	2731	2019	1390
0.2	11349	10498	9154	7884	6518	5182	4174	3353	2551	1839	1210
0.3	11169	10318	8974	7704	6338	5002	3994	3173	2371	1659	1030
0.4	10989	10138	8794	7524	6158	4822	3814	2993	2191	1479	850
0.5	10809	9958	8614	7344	5978	4642	3634	2813	2011	1299	670
0.6	10629	9778	8434	7164	5798	4462	3454	2633	1831	1119	490
0.7	10449	9598	8254	6984	5618	4282	3274	2453	1651	939	310
0.8	10269	9418	8074	6804	5438	4102	3094	2273	1471	759	130
0.9	10089	9238	7894	6624	5258	3922	2914	2093	1291	579	
1.0	9909	9058	7714	6444	5078	3742	2734	1913	1111	399	
1.1	9729	8878	7534	6264	4898	3562	2554	1733	931	219	
1.2	9549	8698	7354	6084	4718	3382	2374	1553	751	39	
1.3	9369	8518	7174	5904	4538	3202	2194	1373	571		
1.4	9189	8338	6994	5724	4358	3022	2014	1193	391		
1.5	9009	8158	6814	5544	4178	2842	1834	1013	211		
1.6	8829	7978	6634	5364	3998	2662	1654	833	31		
1.7	8649	7798	6454	5184	3818	2482	1474	653			
1.8	8469	7618	6274	5004	3638	2302	1294	473			
1.9	8289	7438	6094	4824	3458	2122	1114	293			
2.0	8109	7258	5914	4644	3278	1942	934	113			

TABLE VII Showing Draw Bar Pull of Frisco Locomotives

SHEET 16.

ENGINE No. - 91.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	11185	10651	9368	8089	6806	5487	4463	3601	2824	2130	1478
0.1	10967	10433	9150	7871	6588	5269	4245	3383	2606	1912	1260
0.2	10749	10215	8932	7653	6370	5051	4027	3165	2388	1694	1042
0.3	10531	9997	8714	7435	6152	4833	3809	2947	2170	1476	824
0.4	10313	9779	8496	7217	5934	4615	3591	2729	1952	1258	606
0.5	10095	9561	8278	6999	5716	4397	3373	2511	1734	1040	388
0.6	9877	9343	8060	6781	5498	4179	3155	2293	1516	822	170
0.7	9659	9125	7842	6563	5280	3961	2937	2075	1298	604	
0.8	9441	8907	7624	6345	5062	3743	2719	1857	1080	386	
0.9	9223	8689	7406	6127	4844	3525	2501	1639	862	168	
1.0	9005	8471	7188	5909	4626	3307	2283	1421	644		
1.1	8787	8253	6970	5691	4408	3089	2065	1203	426		
1.2	8569	8035	6752	5473	4190	2871	1847	985	208		
1.3	8351	7817	6534	5255	3972	2653	1629	767			
1.4	8133	7599	6316	5037	3754	2435	1411	549			
1.5	7915	7381	6098	4819	3536	2217	1193	331			
1.6	7697	7163	5880	4601	3318	1999	975	113			
1.7	7479	6945	5662	4383	3100	1781	757				
1.8	7261	6727	5444	4165	2882	1563	539				
1.9	7043	6509	5226	3947	2664	1345	321				
2.0	6825	6291	5008	3729	2446	1127	103				

TABLE VII – Showing Draw Bar Pull of Frisco Locomotives

SHEET – 17.

ENGINE No. – 92.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	11776	10925	9584	8310	6945	5607	4599	3778	2969	2273	1625
0.1	11588	10737	9396	8122	6757	5419	4411	3590	2781	2085	1437
0.2	11400	10549	9208	7934	6569	5231	4223	3402	2593	1897	1249
0.3	11212	10361	9020	7746	6381	5043	4035	3214	2405	1709	1061
0.4	11024	10173	8832	7558	6193	4855	3847	3026	2217	1521	873
0.5	10836	9985	8644	7370	6005	4667	3659	2838	2029	1333	685
0.6	10648	9797	8456	7182	5817	4479	3471	2650	1841	1145	497
0.7	10460	9609	8268	6994	5629	4291	3283	2462	1653	957	309
0.8	10272	9421	8080	6806	5441	4103	3095	2274	1465	769	121
0.9	10084	9233	7892	6618	5253	3915	2907	2086	1277	581	
1.0	9896	9045	7704	6430	5065	3727	2719	1898	1089	393	
1.1	9708	8857	7516	6242	4877	3539	2531	1710	901	205	
1.2	9520	8669	7328	6054	4689	3351	2343	1522	713	17	
1.3	9332	8481	7140	5866	4501	3163	2155	1334	525		
1.4	9144	8293	6952	5678	4313	2975	1967	1146	337		
1.5	8956	8105	6764	5490	4125	2787	1779	958	149		
1.6	8768	7917	6576	5302	3937	2599	1591	770			
1.7	8580	7729	6388	5114	3749	2411	1403	582			
1.8	8392	7541	6200	4926	3561	2223	1215	394			
1.9	8204	7353	6012	4738	3373	2035	1027	206			
2.0	8016	7165	5824	4550	3185	1847	839	18			

ENGINE No. - 93.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	12308	12245	10671	9071	7473	6040	4965	4017	3193	2430	1749
0.1	12096	12033	10459	8859	7261	5828	4753	3805	2981	2218	1537
0.2	11884	11821	10247	8647	7049	5616	4541	3593	2769	2006	1325
0.3	11672	11609	10035	8435	6837	5404	4329	3381	2557	1794	1113
0.4	11460	11397	9823	8223	6625	5192	4117	3169	2345	1582	901
0.5	11248	11185	9611	8011	6413	4980	3905	2957	2133	1370	689
0.6	11036	10973	9399	7799	6201	4768	3693	2745	1921	1158	477
0.7	10824	10761	9187	7587	5989	4556	3481	2533	1709	946	265
0.8	10612	10549	8975	7375	5777	4344	3269	2321	1497	734	53
0.9	10400	10337	8763	7163	5565	4132	3057	2109	1285	522	
1.0	10188	10125	8551	6951	5353	3920	2845	1897	1073	310	
1.1	9976	9913	8339	6739	5141	3708	2633	1685	861	98	
1.2	9764	9701	8127	6527	4929	3496	2421	1473	649		
1.3	9552	9489	7915	6315	4717	3284	2209	1261	437		
1.4	9340	9277	7703	6103	4505	3072	1997	1049	225		
1.5	9128	9065	7491	5891	4293	2860	1785	837	13		
1.6	8916	8853	7279	5679	4181	2648	1573	625			
1.7	8704	8641	7067	5467	3869	2436	1361	413			
1.8	8492	8429	6855	5255	3657	2224	1149	201			
1.9	8280	8217	6643	5043	3445	2012	937				
2.0	8068	8005	6431	4831	3233	1800	725				

ENGINE No. - 94.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	13184	12265	10799	9348	7888	6399	5245	4273	3413	2640	1917
0.1	12946	12027	10561	9110	7650	6161	5007	4035	3175	2402	1679
0.2	12708	11789	10323	8872	7412	5923	4769	3797	2937	2164	1441
0.3	12470	11551	10085	8634	7174	5685	4531	3559	2699	1926	1203
0.4	12232	11313	9847	8396	6936	5447	4293	3321	2461	1688	965
0.5	11994	11075	9609	8158	6698	5209	4055	3083	2223	1450	727
0.6	11756	10837	9371	7920	6460	4971	3817	2845	1985	1212	489
0.7	11518	10599	9133	7682	6222	4733	3579	2607	1747	974	251
0.8	11280	10361	8895	7444	5984	4495	3341	2369	1509	736	13
0.9	11042	10123	8657	7206	5746	4257	3103	2131	1271	498	
1.0	10804	9885	8419	6968	5508	4019	2865	1893	1033	260	
1.1	10566	9647	8181	6730	5270	3781	2627	1655	795	22	
1.2	10328	9409	7943	6492	5032	3543	2389	1417	557		
1.3	10090	9171	7705	6254	4794	3305	2151	1179	319		
1.4	9852	8933	7467	6016	4556	3067	1913	941	81		
1.5	9614	8695	7229	5778	4318	2829	1675	703			
1.6	9376	8457	6991	5540	4080	2591	1437	465			
1.7	9138	8219	6753	5302	3842	2353	1199	227			
1.8	8900	7981	6515	5064	3604	2115	961				
1.9	8662	7743	6277	4826	3366	1877	723				
2.0	8424	7505	6039	4588	3128	1639	485				

TABLE VII. Showing Draw Bar Pull [illegible]

SHEET 20

ENGINE No. 95.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	12636	12570	11092	9431	7792	6310	5204	4229	3389	2610	1912
0.1	12430	12364	10886	9225	7586	6104	4998	4023	3183	2404	1706
0.2	12224	12158	10680	9019	7380	5898	4792	3817	2977	2198	1500
0.3	12018	11952	10474	8813	7174	5692	4586	3611	2771	1992	1294
0.4	11812	11746	10268	8607	6968	5486	4380	3405	2565	1786	1088
0.5	11606	11540	10062	8401	6762	5280	4174	3199	2359	1580	882
0.6	11400	11334	9856	8195	6556	5074	3968	2993	2153	1374	676
0.7	11194	11128	9650	7989	6350	4868	3762	2787	1947	1168	470
0.8	10988	10922	9444	7783	6144	4662	3556	2581	1741	962	264
0.9	10782	10716	9238	7577	5938	4456	3350	2375	1535	756	58
1.0	10576	10510	9032	7371	5732	4250	3144	2169	1329	550	
1.1	10370	10304	8826	7165	5526	4044	2938	1963	1123	344	
1.2	10164	10098	8620	6959	5320	3838	2732	1757	917	138	
1.3	9958	9892	8414	6753	5114	3632	2526	1551	711		
1.4	9752	9686	8208	6547	4908	3426	2320	1345	505		
1.5	9546	9480	8002	6341	4702	3220	2114	1139	299		
1.6	9340	9274	7796	6135	4496	3014	1908	933	93		
1.7	9134	9068	7590	5929	4290	2808	1702	727			
1.8	8928	8862	7384	5723	4084	2602	1496	521			
1.9	8722	8656	7178	5517	3878	2396	1290	315			
2.0	8516	8450	6972	5311	3672	2190	1084	109			

ENGINE No. - 96 To 103.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	13045	12090	10613	9172	7694	6229	5127	4230	3348	2600	1889
0.1	12831	11876	10399	8958	7480	6015	4913	4016	3134	2386	1675
0.2	12617	11662	10185	8744	7266	5801	4699	3802	2920	2172	1461
0.3	12403	11448	9971	8530	7052	5587	4485	3588	2706	1958	1247
0.4	12189	11234	9757	8316	6838	5373	4271	3374	2492	1744	1033
0.5	11975	11020	9543	8102	6624	5159	4057	3160	2278	1530	819
0.6	11761	10806	9329	7888	6410	4945	3843	2946	2064	1316	605
0.7	11547	10592	9115	7674	6196	4731	3629	2732	1850	1102	391
0.8	11333	10378	8901	7460	5982	4517	3415	2518	1636	888	177
0.9	11119	10164	8687	7246	5768	4303	3201	2304	1422	674	
1.0	10905	9950	8473	7032	5554	4089	2987	2090	1208	460	
1.1	10691	9736	8259	6818	5340	3875	2773	1876	994	246	
1.2	10477	9522	8045	6604	5126	3661	2559	1662	780	32	
1.3	10263	9308	7831	6390	4912	3447	2345	1448	566		
1.4	10049	9094	7617	6176	4698	3233	2131	1234	352		
1.5	9835	8880	7403	5962	4484	3019	1917	1020	138		
1.6	9621	8666	7189	5748	4270	2805	1703	806			
1.7	9407	8452	6975	5534	4056	2591	1489	592			
1.8	9193	8238	6761	5320	3842	2377	1275	378			
1.9	8979	8024	6547	5106	3628	2163	1061	164			
2.0	8765	7810	6333	4892	3414	1949	847				

ENGINE No. 104.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	13511	12386	10843	9291	7765	6231	5260	4205	3476	2591	1936
0.1	13319	12194	10651	9099	7573	6039	5068	4013	3284	2399	1744
0.2	13127	12002	10459	8907	7381	5847	4876	3821	3092	2207	1552
0.3	12935	11810	10267	8715	7189	5655	4684	3629	2900	2015	1360
0.4	12743	11618	10075	8523	6997	5463	4492	3437	2708	1823	1168
0.5	12551	11426	9883	8331	6805	5271	4300	3245	2516	1631	976
0.6	12359	11234	9691	8139	6613	5079	4108	3053	2324	1439	784
0.7	12167	11042	9499	7947	6421	4887	3916	2861	2132	1247	592
0.8	11975	10850	9307	7755	6229	4695	3724	2669	1940	1055	400
0.9	11783	10658	9115	7563	6037	4503	3532	2477	1748	863	208
1.0	11591	10466	8923	7371	5845	4311	3340	2285	1556	671	16
1.1	11399	10274	8731	7179	5653	4119	3148	2093	1364	479	
1.2	11207	10082	8539	6987	5461	3927	2956	1901	1172	287	
1.3	11015	9890	8347	6795	5269	3735	2764	1709	980	95	
1.4	10823	9698	8155	6603	5077	3543	2572	1517	788		
1.5	10631	9506	7963	6411	4885	3351	2380	1325	596		
1.6	10439	9314	7771	6219	4693	3159	2188	1133	404		
1.7	10247	9122	7579	6027	4501	2967	1996	941	212		
1.8	10055	8930	7387	5835	4309	2775	1804	749	20		
1.9	9863	8738	7195	5643	4117	2583	1612	557			
2.0	9671	8546	7003	5451	3925	2391	1420	365			

ENGINE No. 106-107

[illegible]	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
	10	15	20	25	30	35	40	45	50	55	60
[illegible]	11472	10912	9570	8300	6936	5600	4592	3771	2971	2266	1632
0.1	11298	10738	9396	8126	6762	5426	4418	3597	2797	2092	1458
0.2	11124	10564	9222	7952	6588	5252	4244	3423	2623	1918	1284
0.3	10950	10390	9048	7778	6414	5078	4070	3249	2449	1744	1110
0.4	10776	10216	8874	7604	6240	4904	3896	3075	2275	1570	936
0.5	10602	10042	8700	7430	6066	4730	3722	2901	2101	1396	762
0.6	10428	9868	8526	7256	5892	4556	3548	2727	1927	1222	588
0.7	10254	9694	8352	7082	5718	4382	3374	2553	1753	1048	414
0.8	10080	9520	8178	6908	5544	4208	3200	2379	1579	874	240
0.9	9906	9346	8004	6734	5370	4034	3026	2205	1405	700	66
1.0	9732	9172	7830	6560	5196	3860	2852	2031	1231	526	
1.1	9558	8998	7656	6386	5022	3686	2678	1857	1057	352	
1.2	9384	8824	7482	6212	4848	3512	2504	1683	883	178	
1.3	9210	8650	7308	6038	4674	3338	2330	1509	709	4	
1.4	9036	8476	7134	5864	4500	3164	2156	1335	535		
1.5	8862	8302	6960	5690	4326	2990	1982	1161	361		
1.6	8688	8128	6786	5516	4152	2816	1808	987	187		
1.7	8514	7954	6612	5342	3978	2642	1634	813	13		
1.8	8340	7780	6438	5168	3804	2468	1460	639			
[illegible]	8166	7606	6264	4994	3630	2294	1286	465			
[illegible]	7992	7432	6090	4820	3456	2120	1112	291			

ENGINE No. 108 to 113.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	12755	12143	10665	9221	7749	6284	5180	4286	3409	2654	1955
0.1	12555	11943	10465	9021	7549	6084	4980	4086	3209	2454	1755
0.2	12355	11743	10265	8821	7349	5884	4780	3886	3009	2254	1555
0.3	12155	11543	10065	8621	7149	5684	4580	3686	2809	2054	1355
0.4	11955	11343	9865	8421	6949	5484	4380	3486	2609	1854	1155
0.5	11755	11143	9665	8221	6749	5284	4180	3286	2409	1654	955
0.6	11555	10943	9465	8021	6549	5084	3980	3086	2209	1454	755
0.7	11355	10743	9265	7821	6349	4884	3780	2886	2009	1254	555
0.8	11155	10543	9065	7621	6149	4684	3580	2686	1809	1054	355
0.9	10955	10343	8865	7421	5949	4484	3380	2486	1609	854	155
1.0	10755	10143	8665	7221	5749	4284	3180	2286	1409	654	
1.1	10555	9943	8465	7021	5549	4084	2980	2086	1209	454	
1.2	10355	9743	8265	6821	5349	3884	2780	1886	1009	254	
1.3	10155	9543	8065	6621	5149	3684	2580	1686	809	54	
1.4	9955	9343	7865	6421	4949	3484	2380	1486	609		
1.5	9755	9143	7665	6221	4749	3284	2180	1286	409		
1.6	9555	8943	7465	6021	4549	3084	1980	1086	209		
1.7	[illegible]	8743	7265	5821	4349	2884	1780	886	9		
1.8	9155	8543	7065	5621	4149	2684	1580	686			
[illegible]	8955	8343	6865	5421	3949	2484	1380	486			
[illegible]	8755	8143	6665	5221	3749	2284	1180	286			

ENGINE No. 114-115

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	13918	12911	11349	9812	8245	6691	5522	4582	3651	2866	2127
0.1	13704	12697	11135	9598	8031	6477	5308	4368	3437	2652	1913
0.2	13490	12483	10921	9384	7817	6263	5094	4154	3223	2438	1699
0.3	13276	12269	10707	9170	7603	6049	4880	3940	3009	2224	1485
0.4	13062	12055	10493	8956	7389	5835	4666	3726	2795	2010	1271
0.5	12848	11841	10279	8742	7175	5621	4452	3512	2581	1796	1057
0.6	12634	11627	10065	8528	6961	5407	4238	3298	2367	1582	843
0.7	12420	11413	9851	8314	6747	5193	4024	3084	2153	1368	629
0.8	12206	11199	9637	8100	6533	4979	3810	2870	1939	1154	415
0.9	11992	10985	9423	7886	6319	4765	3596	2656	1725	940	201
1.0	11778	10771	9209	7672	6105	4551	3382	2442	1511	726	
1.1	11564	10557	8995	7458	5891	4337	3168	2228	1297	512	
1.2	11350	10343	8781	7244	5677	4123	2954	2014	1083	298	
1.3	11136	10129	8567	7030	5463	3909	2740	1800	869	84	
1.4	10922	9915	8353	6816	5249	3695	2526	1586	655		
1.5	10708	9701	8139	6602	5035	3481	2312	1372	441		
1.6	10494	9487	7925	6388	4821	3267	2098	1158	227		
1.7	10280	9273	7711	6174	4607	3053	1884	944	13		
1.8	10066	9059	7497	5960	4393	2839	1670	730			
1.9	9852	8845	7283	5746	4179	2625	1456	516			
2.0	9638	8631	7069	5532	3965	2411	1242	302			

ENGINE No. 130 TO 135

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	13145	13045	11511	9997	8468	6913	5713	4709	3822	3018	2279
0.1	12925	12825	11291	9777	8248	6693	5493	4489	3602	2798	2059
0.2	12705	12605	11071	9557	8028	6473	5273	4269	3382	2578	1839
0.3	12485	12385	10851	9337	7808	6253	5053	4049	3162	2358	1619
0.4	12265	12165	10631	9117	7588	6033	4833	3829	2942	2138	1399
0.5	12045	11945	10411	8897	7368	5813	4613	3609	2722	1918	1179
0.6	11825	11725	10191	8677	7148	5593	4393	3389	2502	1698	959
0.7	11605	11505	9971	8457	6928	5373	4173	3169	2282	1478	739
0.8	11385	11285	9751	8237	6708	5153	3953	2949	2062	1258	519
0.9	11165	11065	9531	8017	6488	4933	3733	2729	1842	1038	299
1.0	10945	10845	9311	7797	6268	4713	3513	2509	1622	818	79
1.1	10725	10625	9091	7577	6048	4493	3293	2289	1402	598	
1.2	10505	10405	8871	7357	5828	4273	3073	2069	1182	378	
1.3	10285	10185	8651	7137	5608	4053	2853	1849	962	158	
1.4	10065	9965	8431	6917	5388	3833	2633	1629	742		
1.5	9845	9745	8211	6697	5168	3613	2413	1409	522		
1.6	9625	9525	7991	6477	4948	3393	2193	1189	302		
1.7	9405	9305	7771	6257	4728	3173	1973	969	82		
1.8	9185	9085	7551	6037	4508	2953	1753	749			
1.9	8965	8865	7331	5817	4288	2733	1533	529			
2.0	8745	8645	7111	5597	4068	2513	1313	309			

TABLE VII Showing Draw Bar Pull of [illegible]

ENGINE No. 136-137.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
	10	15	20	25	30	35	40	45	50	55	60
	12240	12170	11551	10037	8508	6953	5753	4749	3852	3058	2319
	12024	11954	11335	9821	8292	6737	5537	4533	3636	2842	2103
	11808	11738	11119	9605	8076	6521	5321	4317	3420	2626	1887
	11592	11522	10903	9389	7860	6305	5105	4101	3204	2410	1671
	11376	11306	10687	9173	7644	6089	4889	3885	2988	2194	1455
	11160	11090	10471	8957	7428	5873	4673	3669	2772	1978	1239
	10944	10874	10255	8741	7212	5657	4457	3453	2556	1762	1023
	10728	10658	10039	8525	6996	5441	4241	3237	2340	1546	807
	10512	10442	9823	8309	6780	5225	4025	3021	2124	1330	591
	10296	10226	9607	8093	6564	5009	3809	2805	1908	1114	375
	10080	10010	9391	7877	6348	4793	3593	2589	1692	898	159
	9864	9794	9175	7661	6132	4577	3377	2373	1476	682	
	9648	9578	8959	7445	5916	4361	3161	2157	1260	466	
	9432	9362	8743	7229	5700	4145	2945	1941	1044	250	
	9216	9146	8527	7013	5484	3929	2729	1725	828	34	
	9000	8930	8311	6797	5268	3713	2513	1509	612		
	8784	8714	8095	6581	5052	3497	2297	1293	396		
	8568	8498	7879	6365	4836	3281	2081	1077	180		
	8352	8282	7663	6149	4620	3065	1865	861			
	8136	8066	7447	5933	4404	2849	1649	645			
	7920	7850	7231	5717	4188	2633	1433	429			

TABLE VII Showing Draw Bar Pull [illegible]

SHEET 28.

ENGINE No 138 to 143.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	13937	12988	11456	9938	8409	6857	5657	4656	3770	2966	2229
0.1	13721	12772	11240	9722	8193	6641	5441	4440	3554	2750	2013
0.2	13505	12556	11024	9506	7977	6425	5225	4224	3338	2534	1797
0.3	13289	12340	10808	9290	7761	6209	5009	4008	3122	2318	1581
0.4	13073	12124	10592	9074	7545	5993	4793	3792	2906	2102	1365
0.5	12857	11908	10376	8858	7329	5777	4577	3576	2690	1886	1149
0.6	12641	11692	10160	8642	7113	5561	4361	3360	2474	1670	933
0.7	12425	11476	9944	8426	6897	5345	4145	3144	2258	1454	717
0.8	12209	11260	9728	8210	6681	5129	3929	2928	2042	1238	501
0.9	11993	11044	9512	7994	6465	4913	3713	2712	1826	1022	285
1.0	11777	10828	9296	7778	6249	4697	3497	2496	1610	806	69
1.1	11561	10612	9080	7562	6033	4481	3281	2280	1394	590	
1.2	11345	10396	8864	7346	5817	4265	3065	2064	1178	374	
1.3	11129	10180	8648	7130	5601	4049	2849	1848	962	158	
1.4	10913	9964	8432	6914	5385	3833	2633	1632	746		
1.5	10697	9748	8216	6698	5169	3617	2417	1416	530		
1.6	10481	9532	8000	6482	4953	3401	2201	1200	314		
1.7	10265	9316	7784	6266	4737	3185	1985	984	98		
1.8	10049	9100	7568	6050	4521	2969	1769	768			
1.9	9833	8884	7352	5834	4305	2753	1553	552			
2.0	9617	8668	7136	5618	4089	2537	1337	336			

ENGINE No. 144-145.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	14163	13145	11558	9993	8407	6834	5646	4689	3751	2956	2208
0.1	13949	12931	11344	9779	8193	6620	5432	4475	3537	2742	1994
0.2	13735	12717	11130	9565	7979	6406	5218	4261	3323	2528	1780
0.3	13521	12503	10916	9351	7765	6192	5004	4047	3109	2314	1566
0.4	13307	12289	10702	9137	7551	5978	4790	3833	2895	2100	1352
0.5	13093	12075	10488	8923	7337	5764	4576	3619	2681	1886	1138
0.6	12879	11861	10274	8709	7123	5550	4362	3405	2467	1672	924
0.7	12665	11647	10060	8495	6909	5336	4148	3191	2253	1458	710
0.8	12451	11433	9846	8281	6695	5122	3934	2977	2039	1244	496
0.9	12237	11219	9632	8067	6481	4908	3720	2763	1825	1030	282
1.0	12023	11005	9418	7853	6267	4694	3506	2549	1611	816	68
1.1	11809	10791	9204	7639	6053	4480	3292	2335	1397	602	
1.2	11595	10577	8990	7425	5839	4266	3078	2121	1183	388	
1.3	11381	10363	8776	7211	5625	4052	2864	1907	969	174	
1.4	11167	10149	8562	6997	5411	3838	2650	1693	755		
1.5	10953	9935	8348	6783	5197	3624	2436	1479	541		
1.6	10739	9721	8134	6569	4983	3410	2222	1265	327		
1.7	10525	9507	7920	6355	4769	3196	2008	1051	113		
1.8	10311	9293	7706	6141	4555	2982	1794	837			
1.9	10097	9079	7492	5927	4341	2768	1580	623			
2.0	9883	8865	7278	5713	4127	2554	1366	409			

ENGINE No. - 146-147.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	15914	14249	12339	10407	8492	6907	5682	4618	3701	2854	2168
0.1	15704	14039	12129	10197	8282	6697	5472	4408	3491	2644	1958
0.2	15494	13829	11919	9987	8072	6487	5262	4198	3281	2434	1748
0.3	15284	13619	11709	9777	7862	6277	5052	3988	3071	2224	1538
0.4	15074	13409	11499	9567	7652	6067	4842	3778	2861	2014	1328
0.5	14864	13199	11289	9357	7442	5857	4632	3568	2651	1804	1118
0.6	14654	12989	11079	9147	7232	5647	4422	3358	2441	1594	908
0.7	14444	12779	10869	8937	7022	5437	4212	3148	2231	1384	698
0.8	14234	12569	10659	8727	6812	5227	4002	2938	2021	1174	488
0.9	14024	12359	10449	8517	6602	5017	3792	2728	1811	964	278
1.0	13814	12149	10239	8307	6392	4807	3582	2518	1601	754	68
1.1	13604	11939	10029	8097	6182	4597	3372	2308	1391	544	
1.2	13394	11729	9819	7887	5972	4387	3162	2098	1181	334	
1.3	13184	11519	9609	7677	5762	4177	2952	1888	971	124	
1.4	12974	11309	9399	7467	5552	3967	2742	1678	761		
1.5	12764	11099	9189	7257	5342	3757	2532	1468	551		
1.6	12554	10889	8979	7047	5132	3547	2322	1258	341		
[illegible]	12344	10679	8769	6837	4922	3337	2112	1048	131		
[illegible]	12134	10469	8559	6627	4712	3127	1902	838			
[illegible]	11924	10259	8349	6417	4502	2917	1692	628			
2.0	11714	10049	8139	6207	4292	2707	1482	418			

TABLE VII Showing Draw Bar Pull [illegible]

Sheet 31

ENGINE No. 148 to 151

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	14947	13931	12299	10686	9064	7415	6140	5083	4153	3307	2536
0.1	14729	13713	12081	10468	8846	7197	5922	4865	3935	3089	2318
0.2	14511	13495	11863	10250	8628	6979	5704	4647	3717	2871	2100
0.3	14293	13277	11645	10032	8410	6761	5486	4429	3499	2653	1882
0.4	14075	13059	11427	9814	8192	6543	5268	4211	3281	2435	1664
0.5	13857	12841	11209	9596	7974	6325	5050	3993	3063	2217	1446
0.6	13639	12623	10991	9378	7756	6107	4832	3775	2845	1999	1228
0.7	13421	12405	10773	9160	7538	5889	4614	3557	2627	1781	1010
0.8	13203	12187	10555	8942	7320	5671	4396	3339	2409	1563	792
0.9	12985	11969	10337	8724	7102	5453	4178	3121	2191	1345	574
1.0	12767	11751	10119	8506	6884	5235	3960	2903	1973	1127	356
1.1	12549	11533	9901	8288	6666	5017	3742	2685	1755	909	138
1.2	12331	11315	9683	8070	6448	4799	3524	2467	1537	691	
1.3	12113	11097	9465	7852	6230	4581	3306	2249	1319	473	
1.4	11895	10879	9247	7634	6012	4363	3088	2031	1101	255	
1.5	11677	10661	9029	7416	5794	4145	2870	1813	883	37	
1.6	11459	10443	8811	7198	5576	3927	2652	1595	665		
1.7	11241	10225	8593	6980	5358	3709	2434	1377	447		
1.8	11023	10007	8375	6762	5140	3491	2216	1159	229		
1.9	10805	9789	8157	6544	4922	3273	1998	941	11		
2.0	10587	9571	7939	6326	4704	3055	1780	723			

TABLE VII Showing Draw Bar [illegible]

SHEET 3W.

ENGINE No 152-154.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	13164	13094	11935	10373	8795	7193	5961	4917	4014	3194	2434
0.1	12944	12874	11715	10153	8575	6973	5741	4697	3794	2974	2214
0.2	12724	12654	11495	9933	8355	6753	5521	4477	3574	2754	1994
0.3	12504	12434	11275	9713	8135	6533	5301	4257	3354	2534	1774
0.4	12284	12214	11055	9493	7915	6313	5081	4037	3134	2314	1554
0.5	12064	11994	10835	9273	7695	6093	4861	3817	2914	2094	1334
0.6	11844	11774	10615	9053	7475	5873	4641	3597	2694	1874	1114
0.7	11624	11554	10395	8833	7255	5653	4421	3377	2474	1654	894
0.8	11404	11334	10175	8613	7035	5433	4201	3157	2254	1434	674
0.9	11184	11114	9955	8393	6815	5213	3981	2937	2034	1214	454
1.0	10964	10894	9735	8173	6595	4993	3761	2717	1814	994	234
1.1	10744	10674	9515	7953	6375	4773	3541	2497	1594	774	14
1.2	10524	10454	9295	7733	6155	4553	3321	2277	1374	554	
1.3	10304	10234	9075	7513	5935	4333	3101	2057	1154	334	
1.4	10084	10014	8855	7293	5715	4113	2881	1837	934	114	
1.5	9864	9794	8635	7073	5495	3893	2661	1617	714		
1.6	9644	9574	8415	6853	5275	3673	2441	1397	494		
1.7	9424	9354	8195	6633	5055	3453	2221	1177	274		
1.8	9204	9134	7975	6413	4835	3233	2001	957	54		
1.9	8984	8914	7755	6193	4615	3013	1781	737			
2.0	8764	8694	7535	5973	4395	2793	1561	517			

Header spanning speed columns: SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL

TABLE VII. Showing Draw Bar Pull of Frisco Locomotives

ENGINE No - 155.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	13013	11768	10230	8683	7135	5747	4702	3780	2981	2239	1568
0.1	12801	11556	10018	8471	6923	5535	4490	3568	2769	2027	1356
0.2	12589	11344	9806	8259	6711	5323	4278	3356	2557	1815	1144
0.3	12377	11132	9594	8047	6499	5111	4066	3144	2345	1603	932
0.4	12165	10920	9382	7835	6287	4899	3854	2932	2133	1391	720
0.5	11953	10708	9170	7623	6075	4687	3642	2720	1921	1179	508
0.6	11741	10496	8958	7411	5863	4475	3430	2508	1709	967	296
0.7	11529	10284	8746	7199	5651	4263	3218	2296	1497	755	84
0.8	11317	10072	8534	6987	5439	4051	3006	2084	1285	543	
0.9	11105	9860	8322	6775	5227	3839	2794	1872	1073	331	
1.0	10893	9648	8110	6563	5015	3627	2582	1660	861	119	
1.1	10681	9436	7898	6351	4803	3415	2370	1448	649		
1.2	10469	9224	7686	6139	4591	3203	2158	1236	437		
[illegible]	10257	9012	7474	5927	4379	2991	1946	1024	225		
[illegible]	10045	8800	7262	5715	4167	2779	1734	812	13		
[illegible]	9833	8588	7050	5503	3955	2567	1522	600			
[illegible]	9621	8376	6838	5291	3743	2355	1310	388			
[illegible]	9409	8164	6626	5079	3531	2143	1098	176			
[illegible]	9197	7952	6414	4867	3319	1931	886				
[illegible]	8985	7740	6202	4655	3107	1719	674				
[illegible]	8773	7528	5990	4443	2895	1507	462				

ENGINE No. 156.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	11882	11823	11127	9463	7822	6344	5235	4261	3423	2640	1944
0.1	11684	11625	10929	9265	7624	6146	5037	4063	3225	2442	1746
0.2	11486	11427	10731	9067	7426	5948	4839	3865	3027	2244	1548
0.3	11288	11229	10533	8869	7228	5750	4641	3667	2829	2046	1350
0.4	11090	11031	10335	8671	7030	5552	4443	3469	2631	1848	1152
0.5	10892	10833	10137	8473	6832	5354	4245	3271	2433	1650	954
0.6	10694	10635	9939	8275	6634	5156	4047	3073	2235	1452	756
0.7	10496	10437	9741	8077	6436	4958	3849	2875	2037	1254	558
0.8	10298	10239	9543	7879	6238	4760	3651	2677	1839	1056	360
0.9	10100	10041	9345	7681	6040	4562	3453	2479	1641	858	162
1.0	9902	9843	9147	7483	5842	4364	3255	2281	1443	660	
1.1	9704	9645	8949	7285	5644	4166	3057	2083	1245	462	
1.2	9506	9447	8751	7087	5446	3968	2859	1885	1047	264	
1.3	9308	9249	8553	6889	5248	3770	2661	1687	849	66	
1.4	9110	9051	8355	6691	5050	3572	2463	1489	651		
1.5	8912	8853	8157	6493	4852	3374	2265	1291	453		
[illegible]	8714	8655	7959	6295	4654	3176	2067	1093	255		
[illegible]	8516	8457	7761	6097	4456	2978	1869	895	57		
[illegible]	8318	8259	7563	5899	4258	2780	1671	697			
[illegible]	8120	8061	7365	5701	4060	2582	1473	499			
[illegible]	7922	7863	7167	5503	3862	2384	1275	301			

ENGINE No. 157.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
[illegible]	12665	11976	10559	9154	7745	6297	5182	4247	3414	2663	1965
[illegible]	12455	11766	10349	8944	7535	6087	4972	4037	3204	2453	1755
[illegible]	12245	11556	10139	8734	7325	5877	4762	3827	2994	2243	1545
[illegible]	12035	11346	9929	8524	7115	5667	4552	3617	2784	2033	1335
[illegible]	11825	11136	9719	8314	6905	5457	4342	3407	2574	1823	1125
[illegible]	11615	10926	9509	8104	6695	5247	4132	3197	2364	1613	915
0.6	11405	10716	9299	7894	6485	5037	3922	2987	2154	1403	705
0.7	11195	10506	9089	7684	6275	4827	3712	2777	1944	1193	495
[illegible]	10985	10296	8879	7474	6065	4617	3502	2567	1734	983	285
[illegible]	10775	10086	8669	7264	5855	4407	3292	2357	1524	773	75
[illegible]	10565	9876	8459	7054	5645	4197	3082	2147	1314	563	
[illegible]	10355	9666	8249	6844	5435	3987	2872	1937	1104	353	
1.2	10145	9456	8039	6634	5225	3777	2662	1727	894	143	
[illegible]	9935	9246	7829	6424	5015	3567	2452	1517	684		
[illegible]	9725	9036	7619	6214	4805	3357	2242	1307	474		
[illegible]	9515	8826	7409	6004	4595	3147	2032	1097	264		
[illegible]	9305	8616	7199	5794	4385	2937	1822	887	54		
[illegible]	9095	8406	6989	5584	4175	2727	1612	677			
[illegible]	[illegible]	8196	6779	5374	3965	2517	1402	467			
[illegible]	[illegible]	7986	6569	5164	3755	2307	1192	257			
[illegible]	[illegible]	7776	6359	4954	3545	2097	982	47			

SHEET 36

ENGINE No. – 158.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	15418	14368	12684	11015	9349	7643	6331	5239	4279	3414	2615
0.1	15178	14128	12444	10775	9109	7403	6091	4999	4039	3174	2375
0.2	14938	13888	12204	10535	8869	7163	5851	4759	3799	2934	2135
0.3	14698	13648	11964	10295	8629	6923	5611	4519	3559	2694	1895
0.4	14458	13408	11724	10055	8389	6683	5371	4279	3319	2454	1655
0.5	14218	13168	11484	9815	8149	6443	5131	4039	3079	2214	1415
0.6	13978	12928	11244	9575	7909	6203	4891	3799	2839	1974	1175
0.7	13738	12688	11004	9335	7669	5963	4651	3559	2599	1734	935
0.8	13498	12448	10764	9095	7429	5723	4411	3319	2359	1494	695
0.9	13258	12208	10524	8855	7189	5483	4171	3079	2119	1254	455
1.0	13018	11968	10284	8615	6949	5243	3931	2839	1879	1014	215
1.1	12778	11728	10044	8375	6709	5003	3691	2599	1639	774	
1.2	12538	11488	9804	8135	6469	4763	3451	2359	1399	534	
1.3	12298	11248	9564	7895	6229	4523	3211	2119	1159	294	
1.4	12058	11008	9324	7655	5989	4283	2971	1879	919	54	
[illegible]	11818	10768	9084	7415	5749	4043	2731	1639	679		
[illegible]	11578	10528	8844	7175	5509	3803	2491	1399	439		
[illegible]	11338	10288	8604	6935	5269	3563	2251	1159	199		
[illegible]	11098	10048	8364	6695	5029	3323	2011	919			
[illegible]	10858	9808	8124	6455	4789	3083	1771	679			
[illegible]	10618	9568	7884	6215	4549	2843	1531	439			

ENGINE No. -160

SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	15598	14723	12939	11145	9339	7606	6326	5234	4249	3349	2583
0.1	15358	14483	12699	10905	9099	7366	6086	4994	4009	3109	2343
0.2	15118	14243	12459	10665	8859	7126	5846	4754	3769	2869	2103
0.3	14878	14003	12219	10425	8619	6886	5606	4514	3529	2629	1863
0.4	14638	13763	11979	10185	8379	6646	5366	4274	3289	2389	1623
0.5	14398	13523	11739	9945	8139	6406	5126	4034	3049	2149	1383
0.6	14158	13283	11499	9705	7899	6166	4886	3794	2809	1909	1143
0.7	13918	13043	11259	9465	7659	5926	4646	3554	2569	1669	903
0.8	13678	12803	11019	9225	7419	5686	4406	3314	2329	1429	663
0.9	13438	12563	10779	8985	7179	5446	4166	3074	2089	1189	423
1.0	13198	12323	10539	8745	6939	5206	3926	2834	1849	949	183
1.1	12958	12083	10299	8505	6699	4966	3686	2594	1609	709	
1.2	12718	11843	10059	8265	6459	4726	3446	2354	1369	469	
1.3	12478	11603	9819	8025	6219	4486	3206	2114	1129	229	
1.4	12238	11363	9579	7785	5979	4246	2966	1874	889		
1.5	11998	11123	9339	7545	5739	4006	2726	1634	649		
1.6	11758	10883	9099	7305	5499	3766	2486	1394	409		
1.7	11518	10643	8859	7065	5259	3526	2246	1154	169		
1.8	11278	10403	8619	6825	5019	3286	2006	914			
1.9	11038	10163	8379	6585	4779	3046	1766	674			
2.0	10998	9923	8139	6345	4539	2806	1526	434			

TABLE VII Showing Draw Bar Pull of Frisco Locomotives

SHEET - 38.

ENGINE No. - 161.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	13838	12752	11179	9601	8019	6481	5346	4375	3491	2672	1984
0.1	13620	12534	10961	9383	7801	6263	5128	4157	3273	2454	1766
0.2	13402	12316	10743	9165	7583	6045	4910	3939	3055	2236	1548
0.3	13184	12098	10525	8947	7365	5827	4692	3721	2837	2018	1330
0.4	12966	11880	10307	8729	7147	5609	4474	3503	2619	1800	1112
0.5	12748	11662	10089	8511	6929	5391	4256	3285	2401	1582	894
0.6	12530	11444	9871	8293	6711	5173	4038	3067	2183	1364	676
0.7	12312	11226	9653	8075	6493	4955	3820	2849	1965	1146	458
0.8	12094	11008	9435	7857	6275	4737	3602	2631	1747	928	240
0.9	11876	10790	9217	7639	6057	4519	3384	2413	1529	710	22
1.0	11658	10572	8999	7421	5839	4301	3166	2195	1311	492	
1.1	11440	10354	8781	7203	5621	4083	2948	1977	1093	274	
1.2	11222	10136	8563	6985	5403	3855	2730	1759	875	56	
1.3	11004	9918	8345	6767	5185	3647	2512	1541	657		
1.4	10786	9700	8127	6549	4967	3429	2294	1323	439		
1.5	10568	9482	7909	6331	4749	3211	2076	1105	221		
1.6	10350	9264	7691	6113	4531	2993	1858	887			
1.7	10132	9046	7473	5895	4313	2775	1640	669			
1.8	9914	8828	7255	5677	4095	2557	1422	451			
[illegible]	9696	8610	7037	5459	3877	2339	1204	233			
[illegible]	9478	8392	6819	5241	3659	2121	986	15			

ENGINE No. -162.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	14540	13196	11493	9775	8045	6416	5352	4341	3473	2667	1958
0.1	14322	12978	11275	9557	7827	6198	5134	4123	3255	2449	1740
0.2	14104	12760	11057	9339	7609	5980	4916	3905	3037	2231	1522
0.3	13886	12542	10839	9121	7391	5762	4698	3687	2819	2013	1304
0.4	13668	12324	10621	8903	7173	5544	4480	3469	2601	1795	1086
0.5	13450	12106	10403	8685	6955	5326	4262	3251	2383	1577	868
0.6	13232	11888	10185	8467	6737	5108	4044	3033	2165	1359	650
0.7	13014	11670	9967	8249	6519	4890	3826	2815	1947	1141	432
0.8	12796	11452	9747	8031	6301	4672	3608	2597	1729	923	214
0.9	12578	11234	9531	7813	6083	4454	3390	2379	1511	705	
1.0	12360	11016	9313	7595	5865	4236	3172	2161	1293	487	
1.1	12142	10798	9095	7377	5647	4018	2954	1943	1075	269	
1.2	11924	10580	8877	7159	5429	3800	2736	1725	857	51	
1.3	11706	10362	8659	6941	5211	3582	2518	1507	639		
1.4	11488	10144	8441	6723	4993	3364	2300	1289	421		
1.5	11270	9926	8223	6505	4775	3146	2082	1071	203		
1.6	11052	9708	8005	6287	4557	2928	1864	853			
1.7	10834	9490	7787	6069	4339	2710	1646	635			
1.8	10616	9272	7569	5851	4121	2492	1428	417			
1.9	10398	9054	7351	5633	3903	2274	1210	199			
2.0	10180	8836	7133	5415	3685	2056	992				

TABLE VII – Showing Draw Bar Pull of Frisco Locomotives

SHEET-40

ENGINE No. - 182 TO 187.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	17340	16152	13235	12359	10473	8569	7120	5901	4842	3892	3017
0.1	17072	15884	12967	12091	10205	8301	6852	5633	4574	3624	2749
0.2	16804	15616	12699	11823	9937	8033	6584	5365	4306	3356	2481
0.3	16536	15348	12431	11555	9669	7765	6316	5097	4038	3088	2213
0.4	16268	15080	12163	11287	9401	7497	6048	4829	3770	2820	1945
0.5	16000	14812	11895	11019	9133	7229	5780	4561	3502	2552	1677
0.6	15732	14544	11627	10751	8865	6961	5512	4293	3234	2284	1409
0.7	15464	14276	11359	10483	8597	6693	5244	4025	2966	2016	1141
0.8	15196	14008	11091	10215	8329	6425	4976	3757	2698	1748	873
0.9	14928	13740	10823	9947	8061	6157	4708	3489	2430	1480	605
1.0	14660	13472	10555	9679	7793	5889	4440	3221	2162	1212	337
1.1	14392	13204	10287	9411	7525	5621	4172	2953	1894	944	69
1.2	14124	12936	10019	9143	7257	5353	3904	2685	1626	676	
1.3	13856	12668	9751	8875	6989	5085	3636	2417	1358	408	
1.4	13588	12400	9483	8607	6721	4817	3368	2149	1090	140	
1.5	13320	12132	9215	8339	6453	4549	3100	1881	822		
1.6	13052	11864	8947	8071	6185	4281	2832	1613	554		
1.7	12784	11596	8679	7803	5917	4013	2564	1345	286		
1.8	12516	11328	8411	7535	5649	3745	2296	1077	18		
1.9	12248	11060	8143	7267	5381	3477	2028	809			
2.0	11980	10792	7875	6999	5113	3209	1760	541			

TABLE VII - Showing Draw Bar Pull of Frisco Locomotives

ENGINE No. - 188-189.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	17368	16178	14262	12386	10502	8597	7149	5829	4872	3922	3048
0.1	17104	15914	13998	12122	10238	8333	6885	5565	4608	3658	2784
0.2	16840	15650	13734	11858	9974	8069	6621	5301	4344	3394	2520
0.3	16576	15386	13470	11594	9710	7805	6357	5037	4080	3130	2256
0.4	16312	15122	13206	11330	9446	7541	6093	4773	3816	2866	1992
0.5	16048	14858	12942	11066	9182	7277	5829	4509	3552	2602	1728
0.6	15784	14594	12678	10802	8918	7013	5565	4245	3288	2338	1464
0.7	15520	14330	12414	10538	8654	6749	5301	3981	3024	2074	1200
0.8	15256	14066	12150	10274	8390	6485	5037	3717	2760	1810	936
0.9	14992	13802	11886	10010	8126	6221	4773	3453	2496	1546	672
1.0	14728	13538	11622	9746	7862	5957	4509	3189	2232	1282	408
1.1	14464	13274	11358	9482	7598	5693	4245	2925	1968	1018	144
1.2	14200	13010	11094	9218	7334	5429	3981	2661	1704	754	
1.3	13936	12746	10830	8954	7070	5165	3717	2397	1440	490	
1.4	13672	12482	10566	8690	6806	4901	3453	2133	1176	226	
1.5	13408	12218	10302	8426	6542	4637	3189	1869	912		
1.6	13144	11954	10038	8162	6278	4373	2925	1605	648		
1.7	12880	11690	9774	7898	6014	4109	2661	1341	384		
1.8	12616	11426	9510	7634	5750	3845	2397	1077			
1.9	12352	11162	9246	7370	5486	3581	2133	813			
2.0	12088	10898	8982	7106	5222	3317	1869	549			

SHEET 46

ENGINE No. 190 TO 195.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	19333	18013	15893	13826	11723	9629	8017	6691	5525	4487	3537
0.1	19035	17715	15595	13528	11425	9331	7719	6393	5227	4189	3239
0.2	18737	17417	15297	13230	11127	9033	7421	6095	4929	3891	2941
0.3	18439	17119	14999	12932	10829	8735	7123	5797	4631	3593	2643
0.4	18141	16821	14701	12634	10531	8437	6825	5499	4333	3295	2345
0.5	17843	16523	14403	12336	10233	8139	6527	5201	4035	2997	2047
0.6	17545	16225	14105	12038	9935	7841	6229	4903	3737	2699	1749
0.7	17247	15927	13807	11740	9637	7548	5931	4605	3439	2401	1451
0.8	16949	15629	13509	11442	9339	7245	5633	4307	3141	2103	1153
0.9	16651	15331	13211	11144	9041	6947	5335	4009	2843	1805	855
1.0	16353	15033	12913	10846	8743	6649	5037	3711	2545	1507	557
1.1	16055	14735	12615	10548	8445	6351	4739	3413	2247	1209	259
1.2	15757	14437	12317	10250	8147	6053	4441	3115	1949	911	
1.3	15459	14139	12019	9952	7849	5755	4143	2817	1651	613	
1.4	15161	13841	11721	9654	7551	5457	3845	2519	1353	315	
1.5	14863	13543	11423	9356	7253	5159	3547	2221	1055	17	
1.6	14565	13245	11125	9058	6955	4861	3249	1923	757		
1.7	14267	12947	10827	8760	6657	4563	2951	1625	459		
1.8	13969	12649	10529	8462	6359	4265	2653	1327	161		
1.9	13671	12351	10231	8164	6061	3967	2355	1029			
2.0	13373	12053	9933	7866	5763	3669	2057	731			

TABLE VII Showing Draw Bar Pull [illegible]

ENGINE No. 200 TO 204

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	21706	20257	17898	15610	13288	10966	9215	7753	6488	5360	4332
0.1	21424	19975	17616	15328	13006	10684	8933	7471	6206	5078	4050
0.2	21142	19693	17334	15046	12724	10402	8651	7189	5924	4796	3768
0.3	20860	19411	17052	14764	12442	10120	8369	6907	5642	4514	3486
0.4	20578	19129	16770	14482	12160	9838	8087	6625	5360	4232	3204
0.5	20296	18847	16488	14200	11878	9556	7805	6343	5078	3950	2922
0.6	20014	18565	16206	13918	11596	9274	7523	6061	4796	3668	2640
0.7	19732	18283	15924	13636	11314	8992	7241	5779	4514	3386	2358
0.8	19450	18001	15642	13354	11032	8710	6959	5497	4232	3104	2076
0.9	19168	17719	15360	13072	10750	8428	6677	5215	3950	2822	1794
1.0	18886	17437	15078	12790	10468	8146	6395	4933	3668	2540	1512
1.1	18604	17155	14796	12508	10186	7864	6113	4651	3386	2258	1230
1.2	18322	16873	14514	12226	9904	7582	5831	4369	3104	1976	948
1.3	18040	16591	14232	11944	9622	7300	5549	4087	2822	1694	666
1.4	17758	16309	13950	11662	9340	7018	5267	3805	2540	1412	384
1.5	17476	16027	13668	11380	9058	6736	4985	3523	2258	1130	102
1.6	17194	15745	13386	11098	8776	6454	4703	3241	1976	848	
1.7	16912	15463	13104	10816	8494	6172	4421	2959	1694	566	
1.8	16630	15181	12822	10534	8212	5890	4139	2677	1412	284	
1.9	16348	14899	12540	10252	7930	5608	3857	2395	1130	2	
2.0	16066	14617	12258	9970	7648	5326	3575	2113	848		

TABLE VII - Showing Draw Bar Pull of Frisco Locomotives

SHEET - 44.

ENGINE No. 205 TO 219

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	21595	20146	17786	15496	13171	10849	9105	7629	6361	5230	4198
0.1	21293	19844	17484	15194	12869	10547	8803	7327	6059	4928	3896
0.2	20991	19542	17182	14892	12567	10245	8501	7025	5757	4626	3594
0.3	20689	19240	16880	14590	12265	9943	8199	6723	5455	4324	3292
0.4	20387	18938	16578	14288	11963	9641	7897	6421	5153	4022	2990
0.5	20085	18636	16276	13986	11661	9339	7595	6119	4851	3720	2688
0.6	19783	18334	15974	13684	11359	9037	7293	5817	4549	3418	2386
0.7	19481	18032	15672	13382	11057	8735	6991	5515	4247	3116	2084
0.8	19179	17730	15370	13080	10755	8433	6689	5213	3945	2814	1782
0.9	18877	17428	15068	12778	10453	8131	6387	4911	3643	2512	1480
1.0	18575	17126	14766	12476	10151	7829	6085	4609	3341	2210	1178
1.1	18273	16824	14464	12174	9849	7527	5783	4307	3039	1908	876
1.2	17971	16522	14162	11872	9547	7225	5481	4005	2737	1606	574
1.3	17669	16220	13860	11570	9245	6923	5179	3703	2435	1304	272
1.4	17367	15918	13558	11268	8943	6621	4877	3401	2133	1002	
1.5	17065	15616	13256	10966	8641	6319	4575	3099	1831	700	
1.6	16763	15314	12954	10664	8339	6017	4273	2797	1529	398	
1.7	16461	15012	12652	10362	8037	5715	3971	2495	1227	96	
1.8	16159	14710	12350	10060	7735	5413	3669	2193	925		
1.9	15857	14408	12048	9758	7433	5111	3367	1891	623		
2.0	15555	14106	11746	9456	7131	4809	3065	1589	321		

TABLE VII Showing Draw Bar Pull of Frisco Locomotives

SHEET- 45.

ENGINE No. 220 to 229.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	21618	20168	17808	15518	13192	10870	9115	7649	6379	5249	4216
0.1	21316	19866	17506	15216	12890	10568	8813	7347	6077	4947	3914
0.2	21014	19564	17204	14914	12588	10266	8511	7045	5775	4645	3612
0.3	20712	19262	16902	14612	12286	9964	8209	6743	5473	4343	3310
0.4	20410	18960	16600	14310	11984	9662	7907	6441	5171	4041	3008
0.5	20108	18658	16298	14008	11682	9360	7605	6139	4869	3739	2706
0.6	19806	18356	15996	13706	11380	9058	7303	5837	4567	3437	2404
0.7	19504	18054	15694	13404	11078	8756	7001	5535	4265	3135	2102
0.8	19202	17752	15392	13102	10776	8454	6699	5233	3963	2833	1800
0.9	18900	17450	15090	12800	10474	8152	6397	4931	3661	2531	1498
1.0	18598	17148	14788	12498	10172	7850	6095	4629	3359	2229	1196
1.1	18296	16846	14486	12196	9870	7548	5793	4327	3057	1927	894
1.2	17994	16544	14184	11894	9568	7246	5491	4025	2755	1625	592
1.3	17692	16242	13882	11592	9266	6944	5189	3723	2453	1323	290
1.4	17390	15940	13580	11290	8964	6642	4887	3421	2151	1021	
1.5	17088	15638	13278	10988	8662	6340	4585	3119	1849	719	
1.6	16786	15336	12976	10686	8360	6038	4283	2817	1547	417	
1.7	16484	15034	12674	10384	8058	5736	3981	2515	1245	115	
1.8	16182	14732	12372	10082	7756	5434	3679	2213	943		
1.9	15880	14430	12070	9780	7454	5132	3377	1911	641		
2.0	15578	14128	11768	9478	7152	4830	3075	1609	339		

TABLE VII.—Showing Draw Bar Pull of Frisco Locomotives

SHEET-46.

ENGINE No. 300 TO 303.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	18304	16333	14140	11907	9730	8036	6627	5433	4402	3388	2717
0.1	18082	16111	13918	11685	9508	7814	6405	5211	4180	3166	2495
0.2	17860	15889	13696	11463	9286	7592	6183	4989	3958	2944	2273
0.3	17638	15667	13474	11241	9064	7370	5961	4767	3736	2722	2051
0.4	17416	15445	13252	11019	8842	7148	5739	4545	3514	2500	1829
0.5	17194	15223	13030	10797	8620	6926	5517	4323	3292	2278	1607
0.6	16972	15001	12808	10575	8398	6704	5295	4101	3070	2056	1385
0.7	16750	14779	12586	10353	8176	6482	5073	3879	2848	1834	1163
0.8	16528	14557	12364	10131	7954	6260	4851	3657	2626	1612	941
0.9	16306	14335	12142	9909	7732	6038	4629	3435	2404	1390	719
1.0	16084	14113	11920	9687	7510	5816	4407	3213	2182	1168	497
1.1	15862	13891	11698	9465	7288	5594	4185	2991	1960	946	275
1.2	15640	13669	11476	9243	7066	5372	3963	2769	1738	724	53
1.3	15418	13447	11254	9021	6844	5150	3741	2547	1516	502	
1.4	15196	13225	11032	8799	6622	4928	3519	2325	1294	280	
1.5	14974	13003	10810	8577	6400	4706	3297	2103	1072	58	
1.6	14152	12781	10588	8355	6178	4484	3075	1881	850		
1.7	14530	12559	10366	8133	5956	4262	2853	1659	628		
1.8	14308	12337	10144	7911	5734	4040	2631	1437	406		
1.9	14086	12115	9922	7689	5512	3818	2409	1215	184		
2.0	3864	11893	9700	7467	5290	3596	2187	993			

TABLE VII Showing Draw Bar Pull of Frisco Locomotives

SHEET - 47.

ENGINE No. 304 TO 316.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	17729	15811	13702	11528	9425	7775	6406	5249	4244	3354	2598
0.1	17503	15585	13476	11302	9199	7549	6180	5023	4018	3128	2372
0.2	17277	15359	13250	11076	8973	7323	5954	4797	3792	2902	2146
0.3	17051	15133	13024	10850	8747	7097	5728	4571	3566	2676	1920
0.4	16825	14907	12798	10624	8521	6871	5502	4345	3340	2450	1694
0.5	16599	14681	12572	10398	8295	6645	5276	4119	3114	2224	1468
0.6	16373	14455	12346	10172	8069	6419	5050	3893	2888	1998	1242
0.7	16147	14229	12120	9946	7843	6193	4824	3667	2662	1772	1016
0.8	15921	14003	11894	9720	7617	5967	4598	3441	2436	1546	790
0.9	15695	13777	11668	9494	7391	5741	4372	3215	2210	1320	564
1.0	15469	13551	11442	9268	7165	5515	4146	2989	1984	1094	338
1.1	15243	13325	11216	9042	6939	5289	3920	2763	1758	868	112
1.2	15017	13099	10990	8816	6713	5063	3694	2537	1532	642	
1.3	14791	12873	10764	8590	6487	4837	3468	2311	1306	416	
1.4	14565	12647	10538	8364	6261	4611	3242	2085	1080	190	
1.5	14339	12421	10312	8138	6035	4385	3016	1859	854		
1.6	14113	12195	10086	7912	5809	4159	2790	1633	628		
1.7	13887	11969	9860	7686	5583	3933	2564	1407	402		
1.8	13661	11743	9634	7460	5357	3707	2338	1181	176		
1.9	13435	11517	9408	7234	5131	3481	2112	955			
2.0	13209	11291	9182	7008	4905	3255	1886	729			

ENGINE No. 317 to 336.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	17675	15757	13648	11474	9371	7721	6352	5195	4190	3300	2544
0.1	17445	15527	13418	11244	9141	7491	6122	4965	3960	3070	2314
0.2	17215	15297	13188	11014	8911	7261	5892	4735	3730	2840	2084
0.3	16985	15067	12958	10784	8681	7031	5662	4505	3500	2610	1854
0.4	16755	14837	12728	10554	8451	6801	5432	4275	3270	2380	1624
0.5	16525	14607	12498	10324	8221	6571	5202	4045	3040	2150	1394
0.6	16295	14377	12268	10094	7991	6341	4972	3815	2810	1920	1164
0.7	15965	14147	12038	9864	7761	6111	4742	3585	2580	1690	934
0.8	15735	13917	11808	9634	7531	5881	4512	3355	2350	1460	704
0.9	15505	13687	11578	9404	7301	5651	4282	3125	2120	1230	474
1.0	15275	13457	11348	9174	7071	5421	4052	2895	1890	1000	244
1.1	14945	13227	11118	8944	6841	5191	3822	2665	1660	770	14
1.2	14715	12997	10888	8714	6611	4961	3592	2435	1430	540	
1.3	14485	12767	10658	8484	6381	4731	3362	2205	1200	310	
1.4	14255	12537	10428	8254	6151	4501	3132	1975	970	80	
1.5	14025	12307	10198	8024	5921	4271	2902	1745	740		
1.6	13795	12077	9968	7794	5691	4041	2672	1515	510		
1.7	13565	11847	9738	7564	5461	3811	2442	1285	280		
1.8	13335	11617	9508	7334	5231	3581	2212	1055	50		
1.9	13105	11387	9278	7104	5001	3351	1982	825			
2.0	12875	11157	9048	6874	4771	3121	1752	595			

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET- 49.

ENGINE No. 337 to 353.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	18849	16903	14641	12333	10074	8330	6877	5641	4576	3639	2844
0.1	18609	15663	14401	12093	9834	8090	6637	5401	4336	3399	2604
0.2	18369	15423	14161	11853	9594	7850	6397	5161	4096	3159	2364
0.3	18129	15183	13921	11613	9354	7610	6157	4921	3856	2919	2124
0.4	17889	14943	13681	11373	9114	7370	5917	4681	3616	2679	1884
0.5	17649	14703	13441	11133	8874	7130	5677	4441	3376	2439	1644
0.6	17409	14463	13201	10893	8634	6890	5437	4201	3136	2199	1404
0.7	17169	14223	12961	10653	8394	6650	5197	3961	2896	1959	1164
0.8	16929	13983	12721	10413	8154	6410	4957	3721	2656	1719	924
0.9	16689	13743	12481	10173	7914	6170	4717	3481	2416	1479	684
1.0	16449	13503	12241	9933	7674	5930	4477	3241	2176	1239	444
1.1	16209	13263	12001	9693	7434	5690	4237	3001	1936	999	204
1.2	15969	13023	11761	9453	7194	5450	3997	2761	1696	759	
1.3	15729	12783	11521	9213	6954	5210	3757	2521	1456	519	
1.4	15489	12543	11281	8973	6714	4970	3517	2281	1216	279	
1.5	15249	12303	11041	8733	6474	4730	3277	2041	976	39	
1.6	15009	12063	10801	8493	6234	4490	3037	1801	736		
1.7	14769	11823	10561	8253	5994	4250	2797	1561	496		
1.8	14529	11583	10321	8013	5754	4010	2557	1321	256		
1.9	14289	11343	10081	7773	5514	3770	2317	1081	16		
2.0	14049	11103	9841	7533	5274	3530	2077	841			

ENGINE No. 354 TO 358

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
	10	15	20	25	30	35	40	45	50	55	60
0.0	19369	17066	14715	12284	9953	8132	6745	5486	4419	3504	2696
0.1	19119	16816	14465	12034	9703	7882	6495	5236	4169	3254	2446
0.2	18869	16566	14215	11784	9453	7632	6245	4986	3919	3004	2196
0.3	18619	16316	13965	11534	9203	7382	5995	4736	3669	2754	1946
0.4	18369	16066	13715	11284	8953	7132	5745	4486	3419	2504	1696
0.5	18119	15816	13465	11034	8703	6882	5495	4236	3169	2254	1446
0.6	17869	15566	13215	10784	8453	6632	5245	3986	2919	2004	1196
0.7	17619	15316	12965	10534	8203	6382	4995	3736	2669	1754	946
0.8	17369	15066	12715	10284	7953	6132	4745	3486	2419	1504	696
0.9	17119	14816	12465	10034	7703	5882	4495	3236	2169	1254	446
1.0	16869	14566	12215	9784	7453	5632	4245	2986	1919	1004	196
1.1	16619	14316	11965	9534	7203	5382	3995	2736	1669	754	
1.2	16369	14066	11715	9284	6953	5132	3745	2486	1419	504	
1.3	16119	13816	11465	9034	6703	4882	3495	2236	1169	254	
1.4	15869	13566	11215	8784	6453	4632	3245	1986	919	4	
1.5	15619	13316	10965	8534	6203	4382	2995	1736	669		
1.6	15369	13066	10715	8284	5953	4132	2745	1486	419		
1.7	15119	12816	10465	8034	5703	3882	2495	1236	169		
1.8	14869	12566	10215	7784	5453	3632	2245	986			
1.9	14619	12316	9965	7534	5203	3382	1995	736			
2.0	14369	12066	9715	7284	4953	3132	1745	486			

ENGINE No. 359-360.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	20179	17785	15333	12805	10392	8491	7044	5714	4637	3686	2849
0.1	19917	17523	15071	12543	10130	8229	6782	5452	4375	3424	2587
0.2	19655	17261	14809	12281	9868	7967	6520	5190	4113	3162	2325
0.3	19393	16999	14547	12019	9606	7705	6258	4928	3851	2900	2063
0.4	19131	16737	14285	11757	9344	7443	5996	4666	3589	2638	1801
0.5	18869	16475	14023	11495	9082	7181	5734	4404	3327	2376	1539
0.6	18607	16213	13761	11233	8820	6919	5472	4142	3065	2114	1277
0.7	18345	15951	13499	10971	8558	6657	5210	3880	2803	1852	1015
0.8	18083	15689	13237	10709	8296	6395	4948	3618	2541	1590	753
0.9	17821	15427	12975	10447	8034	6133	4686	3356	2279	1328	491
1.0	17559	15165	12713	10185	7772	5871	4424	3094	2017	1066	229
1.1	17297	14903	12451	9923	7510	5609	4162	2832	1755	804	
1.2	17035	14641	12189	9661	7248	5347	3900	2570	1493	542	
1.3	16773	14379	11927	9399	6986	5085	3638	2308	1231	280	
1.4	16511	14117	11665	9137	6724	4823	3376	2046	969	18	
1.5	16249	13855	11403	8875	6462	4561	3114	1784	707		
1.6	15987	13593	11141	8613	6200	4299	2852	1522	445		
1.7	15725	13331	10879	8351	5938	4037	2590	1260	183		
1.8	15463	13069	10617	8089	5676	3775	2328	998			
1.9	15201	12807	10355	7827	5414	3513	2066	736			
2.0	14939	12545	10093	7565	5152	3251	1804	474			

ENGINE No. 361-362.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	22571	19902	17199	14389	11705	9603	8009	6572	5364	4331	3420
0.1	22299	19630	16927	14117	11433	9331	7737	6300	5092	4059	3148
0.2	22027	19358	16655	13845	11161	9059	7465	6028	4820	3787	2876
0.3	21755	19086	16383	13573	10889	8787	7193	5756	4548	3515	2604
0.4	21483	18814	16111	13301	10617	8515	6921	5484	4276	3243	2332
0.5	21211	18542	15839	13029	10345	8243	6649	5212	4004	2971	2060
0.6	20939	18270	15567	12757	10073	7971	6377	4940	3732	2699	1788
0.7	20667	17998	15295	12485	9801	7699	6105	4668	3460	2427	1516
0.8	20395	17726	15023	12213	9529	7427	5833	4396	3188	2155	1244
0.9	20123	17454	14751	11941	9257	7155	5561	4124	2916	1883	972
1.0	19851	17182	14479	11669	8985	6883	5289	3852	2644	1611	700
1.1	19579	16910	14207	11397	8713	6611	5017	3580	2372	1339	428
1.2	19307	16638	13935	11125	8441	6339	4745	3308	2100	1067	156
1.3	19035	16366	13663	10853	8169	6067	4473	3036	1828	795	
1.4	18763	16094	13391	10581	7897	5795	4201	2764	1556	523	
1.5	18491	15822	13119	10309	7625	5523	3929	2492	1284	251	
1.6	18219	15550	12847	10037	7353	5251	3657	2220	1012		
1.7	17947	15278	12575	9765	7081	4979	3385	1948	740		
1.8	17675	15006	12303	9493	6809	4707	3113	1676	468		
1.9	17403	14734	12031	9221	6537	4435	2841	1404	196		
2.0	17131	14462	11759	8949	6265	4163	2569	1132			

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET - 53

ENGINE No. 363-364.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	22648	19975	17275	14469	11789	9688	8098	6664	5461	4431	3524
0.1	22390	19717	17011	14211	11531	9430	7840	6406	5203	4173	3266
0.2	22132	19459	16759	13953	11273	9172	7582	6148	4945	3915	3008
0.3	21874	19201	16501	13695	11015	8914	7324	5890	4687	3657	2750
0.4	21616	18943	16243	13437	10757	8656	7066	5632	4429	3399	2492
0.5	21358	18685	15985	13179	10499	8398	6808	5374	4171	3141	2234
0.6	21100	18427	15727	12921	10241	8140	6550	5116	3913	2883	1976
0.7	20842	18169	15469	12663	9983	7882	6292	4858	3655	2625	1718
0.8	20584	17911	15211	12405	9725	7624	6034	4600	3397	2367	1460
0.9	20326	17653	14953	12147	9467	7366	5776	4342	3139	2109	1202
1.0	20068	17395	14695	11889	9209	7108	5518	4084	2881	1851	944
1.1	19810	17137	14437	11631	8951	6850	5260	3826	2623	1593	686
1.2	19552	16879	14179	11373	8693	6592	5002	3568	2365	1335	428
1.3	19294	16621	13921	11115	8435	6334	4744	3310	2107	1077	170
1.4	19036	16363	13663	10857	8177	6076	4486	3052	1849	819	
1.5	18778	16105	13405	10599	7919	5818	4228	2794	1591	561	
1.6	18520	15847	13147	10341	7661	5560	3970	2536	1333	303	
1.7	18262	15589	12889	10083	7403	5302	3712	2278	1075	45	
1.8	18004	15331	12631	9825	7145	5044	3454	2020	817		
1.9	17746	15073	12373	9567	6887	4786	3196	1762	559		
2.0	17488	14815	12115	9309	6629	4528	2938	1504	301		

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET- 54.

ENGINE No. 400-402-403-404.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	14779	14715	12795	10754	8776	7242	5955	4860	3902	3060	2333
0.1	14567	14503	12583	10542	8564	7030	5743	4648	3690	2848	2121
0.2	14355	14291	12371	10330	8352	6818	5531	4436	3478	2636	1909
0.3	14143	14079	12159	10118	8140	6606	5319	4224	3266	2424	1697
0.4	13931	13867	11947	9906	7928	6394	5107	4012	3054	2212	1485
0.5	13719	13655	11735	9694	7716	6182	4895	3800	2842	2000	1273
0.6	13507	13443	11523	9482	7504	5970	4683	3588	2630	1788	1061
0.7	13295	13231	11311	9270	7292	5758	4471	3376	2418	1576	849
0.8	13083	13019	11099	9058	7080	5546	4259	3164	2206	1364	637
0.9	12871	12807	10887	8846	6868	5334	4047	2952	1994	1152	425
1.0	12659	12595	10675	8634	6656	5122	3835	2740	1782	940	213
1.1	12447	12383	10463	8422	6444	4910	3623	2528	1570	728	1
1.2	12235	12171	10251	8210	6232	4698	3411	2316	1358	516	
1.3	12023	11959	10039	7998	6020	4486	3199	2104	1146	304	
1.4	11811	11747	9827	7786	5808	4274	2987	1892	934	92	
1.5	11599	11535	9615	7574	5596	4062	2775	1680	722		
1.6	11387	11323	9403	7362	5384	3850	2563	1468	510		
1.7	11175	11111	9191	7150	5172	3638	2351	1256	298		
1.8	10963	10899	8979	6938	4960	3426	2139	1044	86		
1.9	10751	10687	8767	6726	4748	3214	1927	832			
2.0	10539	10475	8555	6514	4536	3002	1715	620			

ENGINE No. 401-405-406.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	14755	13148	11355	9524	7726	6342	5165	4165	3287	2508	1833
0.1	14543	12936	11143	9312	7514	6130	4953	3953	3075	2296	1621
0.2	14331	12724	10931	9100	7302	5918	4741	3741	2863	2084	1409
0.3	14119	12512	10719	8888	7090	5706	4529	3529	2651	1872	1197
0.4	13907	12300	10507	8676	6878	5494	4317	3317	2439	1660	985
0.5	13695	12088	10295	8464	6666	5282	4105	3105	2227	1448	773
0.6	13483	11876	10083	8252	6454	5010	3893	2893	2015	1236	561
0.7	13271	11664	9871	8040	6242	4858	3681	2681	1803	1024	349
0.8	13059	11452	9659	7828	6030	4646	3469	2469	1591	812	137
0.9	12847	11240	9447	7616	5818	4434	3257	2257	1379	600	
1.0	12635	11028	9235	7404	5606	4222	3045	2045	1167	388	
1.1	12423	10816	9023	7192	5394	4010	2833	1833	955	176	
1.2	12211	10604	8811	6980	5182	3798	2621	1621	743		
1.3	11999	10392	8599	6768	4970	3586	2409	1409	531		
1.4	11787	10180	8387	6556	4758	3374	2197	1197	319		
1.5	11575	9968	8175	6344	4546	3162	1985	985	107		
1.6	11363	9756	7963	6132	4334	2950	1773	773			
1.7	11151	9544	7751	5920	4122	2738	1561	561			
1.8	10939	9332	7539	5708	3910	2526	1349	349			
1.9	10727	9120	7327	5496	3698	2314	1137	137			
2.0	10515	9108	7115	5284	3486	2102	925				

ENGINE No. 407-408-409.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	14779	14715	13835	11654	9536	7892	6520	5360	4347	3455	2693
0.1	14567	14503	13623	11442	9324	7680	6308	5148	4135	3243	2481
0.2	14355	14291	13411	11230	9112	7468	6096	4936	3923	3031	2269
0.3	14143	14079	13199	11018	8900	7256	5884	4724	3711	2819	2057
0.4	13931	13867	12987	10806	8688	7044	5672	4512	3499	2607	1845
0.5	13719	13655	12775	10594	8476	6832	5460	4300	3287	2395	1633
0.6	13507	13443	12563	10382	8264	6620	5248	4088	3075	2183	1421
0.7	13295	13231	12351	10170	8052	6408	5036	3876	2863	1971	1209
0.8	13083	13019	12139	9958	7840	6196	4824	3664	2651	1759	997
0.9	12871	12807	11927	9746	7628	5984	4612	3452	2439	1547	785
1.0	12659	12595	11715	9534	7416	5772	4400	3240	2227	1335	573
1.1	12447	12383	11503	9322	7204	5560	4188	3028	2015	1123	361
1.2	12235	12171	11291	9110	6992	5348	3976	2816	1803	911	149
1.3	12023	11959	11079	8898	6780	5136	3764	2604	1591	699	
1.4	11811	11747	10867	8686	6568	4924	3552	2392	1379	487	
1.5	11599	11535	10655	8474	6356	4712	3340	2180	1167	275	
1.6	11387	11323	10443	8262	6144	4500	3128	1968	955	63	
1.7	11175	11111	10231	8050	5932	4288	2916	1756	743		
1.8	10963	10899	10019	7838	5720	4076	2704	1544	531		
1.9	10751	10687	9807	7626	5508	3864	2492	1332	319		
2.0	10539	10475	9595	7414	5296	3652	2280	1120	107		

TABLE VII. Showing Draw Bar Pull of [illegible]

SHEET 57.

ENGINE No. 410-411-413-414-415.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	17104	15244	13202	11094	9047	7462	6131	5002	4022	3050	2411
0.1	16874	15014	12972	10864	8817	7232	5901	4772	3792	2820	2181
0.2	16644	14784	12742	10634	8587	7002	5671	4542	3562	2590	1951
0.3	16414	14554	12512	10404	8357	6772	5441	4312	3332	2360	1721
0.4	16184	14324	12282	10174	8127	6542	5211	4082	3102	2130	1491
0.5	15954	14094	12052	9944	7897	6312	4981	3852	2872	1900	1261
0.6	15724	13864	11822	9714	7667	6082	4751	3622	2642	1670	1031
0.7	15494	13634	11592	9484	7437	5852	4521	3392	2412	1440	801
0.8	15264	13404	11362	9254	7207	5622	4291	3162	2182	1210	571
0.9	15034	13174	11132	9024	6977	5392	4061	2932	1952	980	341
1.0	14804	12944	10902	8794	6747	5162	3831	2702	1722	750	111
1.1	14574	12714	10672	8564	6517	4932	3601	2472	1492	520	
1.2	14344	12484	10442	8334	6287	4702	3371	2242	1262	290	
1.3	14114	12254	10212	8104	6057	4472	3141	2012	1032	60	
1.4	13884	12024	9982	7874	5827	4242	2911	1782	802		
1.5	13654	11794	9152	7644	5597	4012	2681	1552	572		
1.6	13424	11564	9522	7414	5367	3782	2451	1322	342		
1.7	13194	11334	9292	7184	5137	3552	2221	1092	112		
1.8	12964	11104	9062	6954	4907	3322	1991	862			
1.9	12734	10874	8832	6724	4677	3092	1761	632			
2.0	12504	10644	8602	6494	4447	2862	1531	402			

TABLE VII. [illegible]

SHEET 58.

ENGINE No. 416.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	16879	15866	13754	11576	9469	7818	6445	5283	4274	3382	2622
0.1	16651	15638	13526	11348	9241	7590	6217	5055	4046	3154	2394
0.2	16423	15410	13298	11120	9013	7362	5989	4827	3818	2926	2166
0.3	16195	15182	13070	10892	8785	7134	5761	4599	3590	2698	1938
0.4	15967	14954	12842	10664	8557	6906	5533	4371	3362	2470	1710
0.5	15739	14726	12614	10436	8329	6678	5305	4143	3134	2242	1482
0.6	15511	14498	12386	10208	8101	6450	5077	3915	2906	2014	1254
0.7	15283	14270	12158	9980	7873	6222	4849	3687	2678	1786	1026
0.8	15055	14042	11930	9752	7645	5994	4621	3459	2450	1558	798
0.9	14827	13814	11702	9524	7417	5766	4393	3231	2222	1330	570
1.0	14599	13586	11474	9296	7189	5538	4165	3003	1994	1102	342
1.1	14371	13358	11246	9068	6961	5310	3937	2775	1766	874	114
1.2	14143	13130	11018	8840	6733	5082	3709	2547	1538	646	
1.3	13915	12902	10790	8612	6505	4854	3481	2319	1310	418	
1.4	13687	12674	10562	8384	6277	4626	3253	2091	1082	190	
[illegible]	13459	12446	10334	8156	6049	4398	3025	1863	854		
[illegible]	13231	12218	10106	7928	5821	4170	2797	1635	626		
[illegible]	13003	11990	9878	7700	5593	3942	2569	1407	398		
[illegible]	12775	11762	9650	7472	5365	3714	2341	1179	170		
[illegible]	12547	11534	9422	7244	5137	3486	2113	951			
[illegible]	12319	11306	9194	7016	4909	3258	1885	723			

TABLE VII Showing Draw Bar Pull of [illegible] Locomotives

ENGINE No. 417 TO 421

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	16413	15883	13771	11591	9486	7834	6458	5295	4283	3391	2629
0.1	16183	15653	13541	11361	9256	7604	6228	5065	4053	3161	2399
0.2	15953	15423	13311	11131	9026	7374	5998	4835	3823	2931	2169
0.3	15723	15193	13081	10901	8796	7144	5768	4605	3593	2701	1939
0.4	15493	14963	12851	10671	8566	6914	5538	4375	3363	2471	1709
0.5	15263	14733	12621	10441	8336	6684	5308	4145	3133	2241	1479
0.6	15033	14503	12391	10211	8106	6454	5078	3915	2903	2011	1249
0.7	14803	14273	12161	9981	7876	6224	4848	3685	2673	1781	1019
0.8	14573	14043	11931	9751	7646	5994	4618	3455	2443	1551	789
0.9	14343	13813	11701	9521	7416	5764	4388	3225	2213	1321	559
1.0	14113	13583	11471	9291	7186	5534	4158	2995	1983	1091	329
1.1	13883	13353	11241	9061	6956	5304	3928	2765	1753	861	99
1.2	13653	13123	11011	8831	6726	5074	3698	2535	1523	631	
1.3	13423	12893	10781	8601	6496	4844	3468	2305	1293	401	
1.4	13193	12663	10551	8371	6266	4614	3238	2075	1063	171	
1.5	12963	12433	10321	8141	6036	4384	3008	1845	833		
1.6	12733	12203	10091	7911	5806	4154	2778	1615	603		
1.7	12503	11973	9861	7681	5576	3924	2548	1385	373		
1.8	12273	11743	9631	7451	5346	3694	2318	1155	143		
1.9	12043	11513	9401	7221	5116	3464	2088	925			
2.0	11813	11283	9171	6991	4886	3234	1858	695			

ENGINE No. 426-427.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	16417	15887	13775	11597	9490	7879	6466	5305	4295	3403	2643
0.1	16191	15661	13549	11371	9264	7653	6240	5079	4069	3177	2417
0.2	15965	15435	13323	11145	9038	7427	6014	4853	3843	2951	2191
0.3	15739	15209	13097	10919	8812	7201	5788	4627	3617	2725	1965
0.4	15513	14983	12871	10693	8586	6975	5562	4401	3391	2499	1739
0.5	15287	14757	12645	10467	8360	6749	5336	4175	3165	2273	1513
0.6	15061	14531	12419	10241	8134	6523	5110	3949	2939	2047	1287
0.7	14835	14305	12193	10015	7908	6297	4884	3723	2713	1821	1061
0.8	14609	14079	11967	9789	7682	6071	4658	3497	2487	1595	835
0.9	14383	13853	11741	9563	7456	5845	4432	3271	2261	1369	609
1.0	14157	13627	11515	9337	7230	5619	4206	3045	2035	1143	383
1.1	13931	13401	11289	9111	7004	5393	3980	2819	1809	917	157
1.2	13705	13175	11063	8885	6778	5167	3754	2593	1583	691	
1.3	13479	12949	10837	8659	6552	4941	3528	2367	1357	465	
1.4	13253	12723	10611	8433	6326	4715	3302	2141	1131	239	
1.5	13027	12497	10385	8207	6100	4489	3076	1915	905	13	
1.6	12801	12271	10159	7981	5874	4263	2850	1689	679		
1.7	12575	12045	9933	7755	5648	4037	2624	1463	453		
1.8	12349	11819	9707	7529	5422	3811	2398	1237	227		
1.9	12123	11593	9481	7303	5196	3585	2172	1011	1		
2.0	11897	11367	9255	7077	4970	3359	1946	785			

ENGINE No. 428 TO 437.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
	10	15	20	25	30	35	40	45	50	55	60
0.0	16968	15356	13413	11444	9481	7722	6418	5276	4299	3400	2603
0.1	16738	15126	13183	11214	9251	7492	6188	5046	4069	3170	2373
0.2	16508	14896	12953	10984	9021	7262	5958	4816	3839	2940	2143
0.3	16278	14666	12723	10754	8791	7032	5728	4586	3609	2710	1913
0.4	16048	14436	12493	10524	8561	6802	5498	4356	3379	2480	1683
0.5	15818	14206	12263	10294	8331	6572	5268	4126	3149	2250	1453
0.6	15588	13976	12033	10064	8101	6342	5038	3896	2919	2020	1223
0.7	15358	13746	11803	9834	7871	6112	4808	3666	2689	1790	993
0.8	15128	13516	11573	9604	7641	5882	4578	3436	2459	1560	763
0.9	14898	13286	11343	9374	7411	5652	4348	3206	2229	1330	533
1.0	14668	13056	11113	9144	7181	5422	4118	2976	1999	1100	303
1.1	14438	12826	10883	8914	6951	5192	3888	2746	1769	870	73
1.2	14208	12596	10653	8684	6721	4962	3658	2516	1539	640	
1.3	13978	12366	10423	8454	6491	4732	3428	2286	1309	410	
1.4	13748	12136	10193	8224	6261	4502	3198	2056	1079	180	
1.5	13518	11906	9963	7994	6031	4272	2968	1826	849		
1.6	13281	11676	9733	7764	5801	4042	2738	1596	619		
1.7	13058	11446	9503	7534	5571	3812	2508	1366	389		
1.8	12828	11216	9273	7304	5341	3582	2278	1136	159		
1.9	12598	10986	9043	7074	5111	3352	2048	906			
2.0	12368	10756	8813	6844	4881	3122	1818	676			

TABLE VII - Showing Draw Bar Pull of Frisco Locomotives

SHEET - 62.

ENGINE No. 438-447.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	17453	16256	14334	12445	10544	8612	7138	5911	4840	3898	3012
0.1	17185	15988	14066	12177	10276	8344	6870	5643	4572	3630	2744
0.2	16917	15720	13798	11909	10008	8076	6602	5375	4304	3362	2476
0.3	16649	15452	13530	11641	9740	7808	6334	5107	4036	3094	2208
0.4	16381	15184	13262	11373	9472	7540	6066	4839	3768	2826	1940
0.5	16113	14916	12994	11105	9204	7272	5798	4571	3500	2558	1672
0.6	15845	14648	12726	10837	8936	7004	5530	4303	3232	2290	1404
0.7	15577	14380	12458	10569	8668	6736	5262	4035	2964	2022	1136
0.8	15309	14112	12190	10301	8400	6468	4994	3767	2696	1754	868
0.9	15041	13844	11922	10033	8132	6200	4726	3499	2428	1486	600
1.0	14773	13576	11654	9765	7864	5932	4458	3231	2160	1218	332
1.1	14505	13308	11386	9497	7596	5664	4190	2963	1892	950	64
1.2	14237	13040	11118	9229	7328	5396	3922	2695	1624	682	
1.3	13969	12772	10850	8961	7060	5128	3654	2427	1356	414	
1.4	13701	12504	10582	8693	6792	4860	3386	2159	1088	146	
1.5	13433	12236	10314	8425	6524	4592	3118	1891	820		
1.6	13165	11968	10046	8157	6256	4324	2850	1623	552		
1.7	12897	11700	9778	7889	5988	4056	2582	1355	284		
1.8	12629	11432	9510	7621	5720	3788	2314	1087	16		
1.9	12361	11164	9242	7353	5452	3520	2046	819			
2.0	12093	10896	8974	7085	5184	3252	1778	551			

ENGINE No. 448 To 458

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	18021	16119	13959	11757	9597	7855	6475	5305	4277	3353	2580
0.1	17785	15883	13723	11521	9361	7619	6239	5069	4041	3117	2344
0.2	17549	15647	13487	11285	9125	7383	6003	4833	3805	2881	2108
0.3	17313	15411	13251	11049	8889	7147	5767	4597	3569	2645	1872
0.4	17077	15175	13015	10813	8653	6911	5531	4361	3333	2409	1636
0.5	16841	14939	12779	10577	8417	6675	5295	4125	3097	2173	1400
0.6	16605	14703	12543	10341	8181	6439	5059	3889	2861	1937	1164
0.7	16369	14467	12307	10105	7945	6203	4823	3653	2625	1701	928
0.8	16133	14231	12071	9869	7709	5967	4587	3417	2389	1465	692
0.9	15897	13995	11835	9633	7473	5731	4351	3181	2153	1229	456
1.0	15661	13759	11599	9397	7237	5495	4115	2945	1917	993	220
1.1	15425	13523	11363	9161	7001	5259	3879	2709	1681	757	
1.2	15189	13287	11127	8925	6765	5023	3643	2473	1445	521	
1.3	14953	13051	10891	8689	6529	4787	3407	2237	1209	285	
1.4	14717	12815	10655	8453	6293	4551	3171	2001	973	49	
1.5	14481	12579	10419	8217	6057	4315	2935	1765	737		
1.6	14245	12343	10183	7981	5821	4079	2699	1529	501		
1.7	14009	12107	9947	7745	5585	3843	2463	1293	265		
1.8	13773	11871	9711	7509	5349	3607	2227	1057	29		
1.9	13537	11635	9475	7273	5113	3371	1991	821			
2.0	13301	11399	9239	7037	4877	3135	1755	585			

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET-64.

ENGINE No. 459 TO 466

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	19318	17279	14999	12637	10337	8500	7032	5805	4720	3748	2945
0.1	19082	17043	14763	12401	10101	8264	6796	5569	4484	3512	2709
0.2	18846	16807	14527	12165	9865	8028	6560	5333	4248	3276	2473
0.3	18610	16571	14291	11929	9629	7792	6324	5097	4012	3040	2237
0.4	18374	16335	14055	11693	9393	7556	6088	4861	3776	2804	2001
0.5	18138	16099	13819	11457	9157	7320	5852	4625	3540	2568	1765
0.6	17902	15863	13583	11221	8921	7084	5616	4389	3304	2332	1529
0.7	17666	15627	13347	10985	8685	6848	5380	4153	3068	2096	1293
0.8	17430	15391	13111	10749	8449	6612	5144	3917	2832	1860	1057
0.9	17194	15155	12875	10513	8213	6376	4908	3681	2596	1624	821
1.0	16958	14919	12639	10277	7977	6140	4672	3445	2360	1388	585
1.1	16722	14683	12403	10041	7741	5904	4436	3209	2124	1152	349
1.2	16486	14447	12167	9805	7505	5668	4200	2973	1888	916	113
1.3	16250	14211	11931	9569	7269	5432	3964	2737	1652	680	
1.4	16014	13975	11695	9333	7033	5196	3728	2501	1416	444	
1.5	15778	13739	11459	9097	6797	4960	3492	2265	1180	208	
1.6	15542	13503	11223	8861	6561	4724	3256	2029	944		
1.7	15306	13267	10987	8625	6325	4488	3020	1793	708		
1.8	15070	13031	10751	8389	6089	4252	2784	1557	472		
1.9	14834	12795	10515	8153	5853	4016	2548	1321	236		
2.0	14598	12559	10279	7917	5617	3780	2312	1085			

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET-65.

ENGINE No. 487 to 490.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	18759	16871	14700	12459	10215	8348	6892	5657	4590	3629	2793
0.1	18481	16593	14422	12181	9937	8070	6614	5379	4312	3351	2515
0.2	18203	16315	14144	11903	9659	7792	6336	5101	4034	3073	2237
0.3	17925	16037	13866	11625	9381	7514	6058	4823	3756	2795	1959
0.4	17647	15759	13588	11347	9103	7236	5780	4545	3478	2517	1681
0.5	17369	15481	13310	11069	8825	6958	5502	4267	3200	2239	1403
0.6	17091	15203	13032	10791	8547	6680	5224	3989	2922	1961	1125
0.7	16813	14925	12754	10513	8269	6402	4946	3711	2644	1683	847
0.8	16535	14647	12476	10235	7991	6124	4668	3433	2366	1405	569
0.9	16257	14369	12198	9957	7713	5846	4390	3155	2088	1127	291
1.0	15979	14091	11920	9679	7435	5568	4112	2877	1810	849	13
1.1	15701	13813	11642	9401	7157	5290	3834	2599	1532	571	
1.2	15423	13535	11364	9123	6879	5012	3556	2321	1254	293	
1.3	15145	13257	11086	8845	6601	4734	3278	2043	976	15	
1.4	14867	12979	10808	8567	6323	4456	3000	1765	698		
1.5	14589	12701	10530	8289	6045	4178	2722	1487	420		
1.6	14311	12423	10252	8011	5767	3900	2444	1209	142		
1.7	14033	12145	9974	7733	5489	3622	2166	931			
1.8	13755	11867	9696	7455	5211	3344	1888	653			
1.9	13477	11589	9418	7177	4933	3066	1610	375			
2.0	13199	11311	9140	6899	4655	2788	1332	97			

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET- 66.

ENGINE No. 491 to 500

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL.										
	10	15	20	25	30	35	40	45	50	55	60
0.0	20114	17559	14975	12344	9830	8106	6639	5423	4341	3438	2689
0.1	19870	17315	14731	12100	9586	7862	6395	5179	4097	3194	2445
0.2	19626	17071	14487	11856	9342	7618	6151	4935	3853	2950	2201
0.3	19382	16827	14243	11612	9098	7374	5907	4691	3609	2706	1957
0.4	19138	16583	13999	11368	8854	7130	5663	4447	3365	2462	1713
0.5	18894	16339	13755	11124	8610	6886	5419	4203	3121	2218	1469
0.6	18650	16095	13511	10880	8366	6642	5175	3959	2877	1974	1225
0.7	18406	15851	13267	10636	8122	6398	4931	3715	2633	1730	981
0.8	18162	15607	13023	10392	7878	6154	4687	3471	2389	1486	737
0.9	17918	15363	12779	10148	7634	5910	4443	3227	2145	1242	493
1.0	17674	15119	12535	9904	7390	5666	4199	2983	1901	998	249
1.1	17430	14875	12291	9660	7146	5422	3955	2739	1657	754	5
1.2	17186	14631	12047	9416	6902	5178	3711	2495	1413	510	
1.3	16942	14387	11803	9172	6658	4934	3467	2251	1169	266	
1.4	16698	14143	11559	8928	6414	4690	3223	2007	925	22	
1.5	16454	13899	11315	8684	6170	4446	2979	1763	681		
1.6	16210	13655	11071	8440	5926	4202	2735	1519	437		
1.7	15966	13411	10827	8196	5682	3958	2491	1275	193		
1.8	15722	13167	10583	7952	5438	3714	2247	1031			
1.9	15478	12923	10339	7708	5194	3470	2003	787			
2.0	15234	12679	10095	7464	4950	3226	1759	543			

ENGINE No. 501 TO 504, 506-515.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	20812	18175	15500	12790	10205	8416	6915	5663	4546	3623	2863
0.1	20566	17929	15254	12544	9959	8170	6669	5417	4300	3377	2617
0.2	20320	17683	15008	12298	9713	7924	6423	5171	4054	3131	2371
0.3	20074	17437	14762	12052	9467	7678	6177	4925	3808	2885	2125
0.4	19828	17191	14516	11806	9221	7432	5931	4679	3562	2639	1879
0.5	19582	16945	14270	11560	8975	7186	5685	4433	3316	2393	1633
0.6	19336	16699	14024	11314	8729	6940	5439	4187	3070	2147	1387
0.7	19090	16453	13778	11068	8483	6694	5193	3941	2824	1901	1141
0.8	18844	16207	13532	10822	8237	6448	4947	3695	2578	1655	895
0.9	18598	15961	13286	10576	7991	6202	4701	3449	2332	1409	649
1.0	18352	15715	13040	10330	7745	5956	4455	3203	2086	1163	403
1.1	18106	15469	12794	10084	7499	5710	4209	2957	1840	917	157
1.2	17860	15223	12548	9838	7253	5464	3963	2711	1594	671	
1.3	17614	14977	12302	9592	7007	5218	3717	2465	1348	425	
1.4	17368	14731	12056	9346	6761	4972	3471	2219	1102	179	
1.5	17122	14485	11810	9100	6515	4726	3225	1973	856		
1.6	16876	14239	11564	8854	6269	4480	2979	1727	610		
1.7	16630	13993	11318	8608	6023	4234	2733	1481	364		
1.8	16384	13747	11072	8362	5777	3988	2487	1235	118		
1.9	16138	13501	10826	8116	5531	3742	2241	989			
2.0	15892	13255	10580	7870	5285	3496	1995	743			

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET- 68

ENGINE No. 516 TO 520.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	27595	24852	21734	18516	15278	12622	10569	8776	7294	5968	4817
0.1	27213	24470	21352	18134	14896	12240	10187	8394	6912	5586	4435
0.2	26831	24088	20970	17752	14514	11858	9805	8012	6530	5204	4053
0.3	26449	23706	20588	17370	14132	11476	9423	7630	6148	4822	3671
0.4	26067	23324	20206	16988	13750	11094	9041	7248	5766	4440	3289
0.5	25685	22942	19824	16606	13368	10712	8659	6866	5384	4058	2907
0.6	25303	22560	19442	16224	12986	10330	8277	6484	5002	3676	2525
0.7	24921	22178	19060	15842	12604	9948	7895	6102	4620	3294	2143
0.8	24539	21796	18678	15460	12222	9566	7513	5720	4238	2912	1761
0.9	24157	21414	18296	15078	11840	9184	7131	5338	3856	2530	1379
1.0	23775	21032	17914	14696	11458	8802	6749	4956	3474	2148	997
1.1	23393	20650	17532	14314	11076	8420	6367	4574	3092	1766	615
1.2	23011	20268	17150	13932	10694	8038	5985	4192	2710	1384	233
1.3	22629	19886	16768	13550	10312	7656	5603	3810	2328	1002	
1.4	22247	19504	16386	13168	9930	7274	5221	3428	1946	620	
1.5	21865	19122	16004	12786	9548	6892	4839	3046	1564	238	
1.6	21483	18740	15622	12404	9166	6510	4457	2664	1182		
1.7	21101	18358	15240	12022	8784	6128	4075	2282	800		
1.8	20719	17976	14858	11640	8402	5746	3693	1900	418		
1.9	20337	17594	14476	11258	8020	5364	3311	1518	36		
2.0	19955	17212	14094	10876	7638	4982	2929	1136			

TABLE VII Showing Draw Bar Pull [illegible]

Sheet [illegible]

ENGINE No. [illegible] to 530.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
	10	15	20	25	30	35	40	45	50	55	60
[illegible]	27606	24856	21752	18639	15308	12656	10589	8829	7354	6037	4487
[illegible]	27252	24502	21398	18285	14954	12302	10235	8475	7000	5683	4133
[illegible]	26898	24148	21044	17931	14600	11948	9881	8121	6646	5329	3779
[illegible]	26544	23794	20690	17577	14246	11594	9527	7767	6292	4975	3425
[illegible]	26190	23440	20336	17223	13892	11240	9173	7413	5938	4621	3071
[illegible]	25836	23086	19982	16869	13538	10886	8819	7059	5584	4267	2717
0.6	25482	22732	19628	16515	13184	10532	8465	6705	5230	3913	2363
0.7	25128	22378	19274	16161	12830	10178	8111	6351	4876	3559	2009
0.8	24774	22024	18920	15807	12476	9824	7757	5997	4522	3205	1655
0.9	24420	21670	18566	15453	12122	9470	7403	5643	4168	2851	1301
1.0	24066	21316	18212	15099	11768	9116	7049	5289	3814	2497	947
1.1	23712	20962	17858	14745	11414	8762	6695	4935	3460	2143	593
1.2	23358	20608	17504	14391	11060	8408	6341	4581	3106	1789	239
1.3	23004	20254	17150	14037	10706	8054	5987	4227	2752	1435	
1.4	22650	19900	16796	13683	10352	7700	5633	3873	2398	1081	
1.5	22296	19546	16442	13329	9998	7346	5279	3519	2044	727	
1.6	21942	19192	16088	12975	9644	6992	4925	3165	1690	373	
1.7	21588	18838	15734	12621	9290	6638	4571	2811	1336	19	
1.8	21234	18484	15380	12267	8936	6284	4217	2457	982		
1.9	20880	18130	15026	11913	8582	5930	3863	2103	628		
2.0	20526	17776	14672	11559	8228	5576	3509	1749	274		

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET- 70

ENGINE No. 539 TO 548

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	21283	19869	17552	15278	12994	10699	8934	7481	6223	5106	4085
0.1	20981	19567	17250	14976	12692	10397	8632	7179	5921	4804	3783
0.2	20679	19265	16948	14674	12390	10095	8330	6877	5619	4502	3481
0.3	20377	18963	16646	14372	12088	9793	8028	6575	5317	4200	3179
0.4	20075	18661	16344	14070	11786	9491	7726	6273	5015	3898	2877
0.5	19773	18359	16042	13768	11484	9189	7424	5971	4713	3596	2575
0.6	19471	18057	15740	13466	11182	8887	7122	5669	4411	3294	2273
0.7	19169	17755	15438	13164	10880	8585	6820	5367	4109	2992	1971
0.8	18867	17453	15136	12862	10578	8283	6518	5065	3807	2690	1669
0.9	18565	17151	14834	12560	10276	7981	6216	4763	3505	2388	1367
1.0	18263	16849	14532	12258	9974	7679	5914	4461	3203	2086	1065
1.1	17961	16547	14230	11956	9672	7377	5612	4159	2901	1784	763
1.2	17659	16245	13928	11654	9370	7075	5310	3857	2599	1482	461
1.3	17357	15943	13626	11352	9068	6773	5008	3555	2297	1180	159
1.4	17055	15641	13324	11050	8766	6471	4706	3253	1995	878	
1.5	16753	15339	13022	10748	8464	6169	4404	2951	1693	576	
1.6	16451	15037	12720	10446	8162	5867	4102	2649	1391	274	
1.7	16149	14735	12418	10144	7860	5565	3800	2347	1089		
1.8	15847	14433	12116	9842	7558	5263	3498	2045	787		
1.9	15545	14131	11814	9540	7256	4961	3196	1743	485		
2.0	15243	13829	11512	9238	6954	4659	2894	1441	183		

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET-71.

ENGINE No. 549 to 557.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	26319	23711	21739	17683	14602	12073	10109	8436	7024	5753	4653
0.1	25993	23385	21413	17357	14276	11747	9783	8110	6698	5427	4327
0.2	25667	23059	21087	17031	13950	11421	9457	7784	6372	5101	4001
0.3	25341	22733	20761	16705	13624	11095	9131	7458	6046	4775	3675
0.4	25015	22407	20435	16379	13298	10769	8805	7132	5720	4449	3349
0.5	24689	22081	20109	16053	12972	10443	8479	6806	5394	4123	3023
0.6	24363	21755	19783	15727	12646	10117	8153	6480	5068	3797	2697
0.7	24037	21429	19457	15401	12320	9791	7827	6154	4742	3471	2371
0.8	23711	21103	19131	15075	11994	9465	7501	5828	4416	3145	2045
0.9	23385	20777	18805	14749	11668	9139	7175	5502	4090	2819	1719
1.0	23059	20451	18479	14423	11342	8813	6849	5176	3764	2493	1393
1.1	22733	20125	18153	14097	11016	8487	6523	4850	3438	2167	1067
1.2	22407	19799	17827	13771	10690	8161	6197	4524	3112	1841	741
1.3	22081	19473	17501	13445	10364	7835	5871	4198	2786	1515	415
1.4	21755	19147	17175	13119	10038	7509	5545	3872	2460	1189	89
1.5	21429	18821	16849	12793	9712	7183	5219	3546	2134	863	
1.6	21103	18495	16523	12467	9386	6857	4893	3220	1808	537	
1.7	20777	18169	16197	12141	9060	6531	4567	2894	1482	211	
1.8	20451	17843	15871	11815	8734	6205	4241	2568	1156		
1.9	20125	17517	15545	11489	8408	5879	3915	2242	830		
2.0	19799	17191	15219	11163	8082	5553	3589	1916	504		

ENGINE No. 558 to 567.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
	10	15	20	25	30	35	40	45	50	55	60
0.0	24826	22356	19501	16588	13660	11246	9380	7735	6376	5153	4090
0.1	24458	21988	19133	16220	13292	10878	9012	7367	6008	4785	3722
0.2	24090	21620	18765	15852	12924	10510	8644	6999	5640	4417	3354
0.3	23722	21252	18397	15484	12556	10142	8276	6631	5272	4049	2986
0.4	23354	20884	18029	15116	12188	9774	7908	6263	4904	3681	2618
0.5	22986	20516	17661	14748	11820	9406	7540	5895	4536	3313	2250
0.6	22618	20148	17293	14380	11452	9038	7172	5527	4168	2945	1882
0.7	22250	19780	16925	14012	11084	8670	6804	5159	3800	2577	1514
0.8	21882	19412	16557	13644	10716	8302	6436	4791	3432	2209	1146
0.9	21514	19044	16189	13276	10348	7934	6068	4423	3064	1841	778
1.0	21146	18676	15821	12908	9980	7566	5700	4055	2696	1473	410
1.1	20778	18298	15453	12540	9612	7198	5332	3687	2328	1105	42
1.2	20410	17940	15085	12172	9244	6830	4964	3319	1960	737	
1.3	20042	17572	14717	11804	8876	6462	4596	2951	1592	369	
1.4	19674	17194	14349	11436	8508	6094	4228	2583	1224	1	
1.5	19306	16836	13981	11068	8140	5726	3860	2215	856		
1.6	18938	16468	13613	10700	7772	5358	3492	1847	488		
1.7	18570	16100	13245	10332	7404	4990	3124	1479	120		
1.8	18202	15732	12877	9964	7036	4622	2756	1111			
1.9	17834	15364	12509	9596	6668	4254	2388	743			
2.0	17466	14996	12141	9228	6300	3886	2020	375			

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET-73

ENGINE No. 568 TO 572.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	24875	22408	19555	16646	13726	11312	9445	7815	6459	5145	4180
0.1	24529	22062	19209	16300	13380	10966	9099	7469	6113	4799	3834
0.2	24183	21716	18863	15954	13034	10620	8753	7123	5767	4453	3488
0.3	23837	21370	18517	15608	12688	10274	8407	6777	5421	4107	3142
0.4	23491	21024	18171	15262	12342	9928	8061	6431	5075	3761	2796
0.5	23145	20678	17825	14916	11996	9582	7715	6085	4729	3415	2450
0.6	22799	20332	17479	14570	11650	9236	7369	5739	4383	3069	2104
0.7	22453	19986	17133	14224	11304	8890	7023	5393	4037	2723	1758
0.8	22107	19640	16787	13878	10958	8544	6677	5047	3691	2377	1412
0.9	21761	19294	16441	13532	10612	8198	6331	4701	3345	2031	1066
1.0	21415	18948	16095	13186	10266	7852	5985	4355	2999	1685	720
1.1	21069	18602	15749	12840	9920	7506	5639	4009	2553	1339	374
1.2	20723	18256	15403	12494	9574	7160	5293	3563	2307	993	28
1.3	20377	17910	15057	12148	9228	6814	4947	3317	1961	647	
1.4	20031	17564	14711	11802	8882	6468	4601	2971	1615	301	
1.5	19685	17218	14365	11456	8536	6122	4255	2625	1269		
1.6	19339	16872	14019	11110	8190	5776	3909	2279	923		
1.7	18993	16526	13673	10764	7844	5430	3563	1933	577		
1.8	18647	16180	13327	10418	7498	5084	3217	1587	231		
1.9	18301	15834	12981	10072	7152	4738	2871	1241			
2.0	17955	15488	12635	9726	6806	4392	2525	895			

ENGINE No. 573-574.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
	10	15	20	25	30	35	40	45	50	55	60
0.0	23400	21068	18370	15599	12809	10538	8740	7226	5933	4773	3767
0.1	23070	20738	18040	15269	12479	10208	8410	6896	5603	4443	3437
0.2	22740	20408	17710	14939	12149	9878	8080	6566	5273	4113	3107
0.3	22410	20078	17380	14609	11819	9548	7750	6236	4943	3783	2777
0.4	22080	19748	17050	14279	11489	9218	7420	5906	4613	3453	2447
0.5	21750	19418	16720	13949	11159	8888	7090	5576	4283	3123	2117
0.6	21420	19088	16390	13619	10829	8558	6760	5246	3953	2793	1787
0.7	21090	18758	16060	13289	10499	8228	6430	4916	3623	2463	1457
0.8	20760	18428	15730	12959	10169	7898	6100	4586	3293	2133	1127
0.9	20430	18098	15400	12629	9839	7568	5770	4256	2963	1803	797
1.0	20100	17768	15070	12299	9509	7238	5440	3926	2633	1473	467
1.1	19770	17438	14740	11969	9179	6908	5110	3596	2303	1143	137
1.2	19440	17108	14410	11639	8849	6578	4780	3266	1973	813	
1.3	19110	16778	14080	11309	8519	6248	4450	2936	1643	483	
1.4	18780	16448	13750	10979	8189	5918	4120	2606	1313	153	
1.5	18450	16118	13420	10649	7859	5588	3790	2276	983		
1.6	18120	15788	13090	10319	7529	5258	3460	1946	653		
1.7	17790	15458	12760	9989	7199	4928	3130	1616	323		
1.8	17460	15128	12430	9659	6869	4598	2800	1286			
1.9	17130	14798	12100	9329	6539	4268	2470	956			
2.0	16800	14468	11770	8999	6209	3938	2140	626			

ENGINE No. 575 to 584.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	29037	25424	21749	18037	14459	12047	10020	8344	6872	5660	4680
0.1	28737	25124	21449	17737	14159	11747	9720	8044	6572	5360	4380
0.2	28437	24824	21149	17437	13859	11447	9420	7744	6272	5060	4080
0.3	28137	24524	20849	17137	13559	11147	9120	7444	5972	4760	3780
0.4	27837	24224	20549	16837	13259	10847	8820	7144	5672	4460	3480
0.5	27537	23924	20249	16537	12959	10547	8520	6844	5372	4160	3180
0.6	27237	23624	19949	16237	12659	10247	8220	6544	5072	3860	2880
0.7	26937	23324	19649	15937	12359	9947	7920	6244	4772	3560	2580
0.8	26637	23024	19349	15637	12059	9647	7620	5944	4472	3260	2280
0.9	26337	22724	19049	15337	11759	9347	7320	5644	4172	2960	1980
1.0	26037	22424	18749	15037	11459	9047	7020	5344	3872	2660	1680
1.1	25737	22124	18449	14737	11159	8747	6720	5044	3572	2360	1380
1.2	25437	21824	18149	14437	10859	8447	6420	4744	3272	2060	1080
1.3	25137	21524	17849	14137	10559	8147	6120	4444	2972	1760	780
1.4	24837	21224	17549	13837	10259	7847	5820	4144	2672	1460	480
1.5	24537	20924	17249	13537	9959	7547	5520	3844	2372	1160	180
1.6	24237	20624	16949	13237	9659	7247	5220	3544	2072	860	
1.7	23937	20324	16649	12937	9359	6947	4920	3244	1772	560	
1.8	23637	20024	16349	12637	9059	6647	4620	2944	1472	260	
1.9	23337	19724	16049	12337	8759	6347	4320	2644	1172		
2.0	23037	19424	15749	12037	8459	6047	4020	2344	872		

ENGINE No. 585 to 594.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	26240	23631	20662	17605	14527	11998	10027	8352	6954	5682	4593
0.1	25908	23299	20330	17273	14195	11666	9695	8020	6622	5350	4261
0.2	25576	22967	19998	16941	13863	11334	9363	7688	6290	5018	3929
0.3	25244	22635	19666	16609	13531	11002	9031	7356	5958	4686	3597
0.4	24912	22303	19334	16277	13199	10670	8699	7024	5626	4354	3265
0.5	24580	21971	19002	15945	12867	10338	8367	6692	5294	4022	2933
0.6	24248	21639	18670	15613	12535	10006	8035	6360	4962	3690	2601
0.7	23916	21307	18338	15281	12203	9674	7703	6028	4630	3358	2269
0.8	23584	20975	18006	14949	11871	9342	7371	5696	4298	3026	1937
0.9	23252	20643	17674	14617	11539	9010	7039	5364	3966	2694	1605
1.0	22920	20311	17342	14285	11207	8678	6707	5032	3634	2362	1273
1.1	22588	19979	17010	13953	10875	8346	6375	4700	3302	2030	941
1.2	22256	19647	16678	13621	10543	8014	6043	4368	2970	1698	609
1.3	21924	19315	16346	13289	10211	7682	5711	4036	2638	1366	277
1.4	21592	18983	16014	12957	9879	7350	5379	3704	2306	1034	
1.5	21260	18651	15682	12625	9547	7018	5047	3372	1974	702	
1.6	20928	18319	15350	12293	9215	6686	4715	3040	1642	370	
1.7	20596	17987	15018	11961	8883	6354	4383	2708	1310	38	
1.8	20264	17655	14686	11624	8551	6022	4051	2376	978		
1.9	19932	17323	14354	11297	8219	5690	3719	2044	646		
2.0	19600	16991	14022	10965	7887	5358	3387	1712	314		

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET-77

ENGINE No. 595 to 599, 669 to 693.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	26257	23647	20678	17620	14542	12012	10041	8376	6967	5694	4604
0.1	25927	23317	20348	17290	14212	11682	9711	8046	6637	5364	4274
0.2	25597	22987	20018	16960	13882	11352	9381	7716	6307	5034	3944
0.3	25267	22657	19688	16630	13552	11022	9051	7386	5977	4704	3614
0.4	24937	22327	19358	16300	13222	10692	8721	7056	5647	4374	3284
0.5	24607	21997	19028	15970	12892	10362	8391	6726	5317	4044	2954
0.6	24277	21667	18698	15640	12562	10032	8061	6396	4987	3714	2624
0.7	23947	21337	18368	15310	12232	9702	7731	6066	4657	3384	2294
0.8	23617	21007	18038	14980	11902	9372	7401	5736	4327	3054	1964
0.9	23287	20677	17708	14650	11572	9042	7071	5406	3997	2724	1634
1.0	22957	20347	17378	14320	11242	8712	6741	5076	3667	2394	1304
1.1	22627	20017	17048	13990	10912	8382	6411	4746	3337	2064	974
1.2	22297	19687	16718	13660	10582	8052	6081	4416	3007	1734	644
1.3	21967	19357	16388	13330	10252	7722	5751	4086	2677	1404	314
1.4	21637	19027	16058	13000	9922	7392	5421	3756	2347	1074	
1.5	21307	18697	15728	12670	9592	7062	5091	3426	2017	744	
1.6	20977	18367	15398	12340	9262	6732	4761	3096	1687	414	
1.7	20647	18037	15068	12010	8932	6402	4431	2766	1357	84	
1.8	20317	17707	14738	11680	8602	6072	4101	2436	1027		
1.9	19987	17377	14408	11350	8272	5742	3771	2106	697		
2.0	19657	17047	14078	11020	7942	5412	3441	1776	367		

ENGINE No. 600 TO 604.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	24400	22137	19326	16558	13728	11247	9410	7808	6447	5248	4205
0.1	24062	21799	18988	16220	13390	10909	9072	7470	6109	4910	3867
0.2	23724	21461	18650	15882	13052	10571	8734	7132	5771	4572	3529
0.3	23386	21123	18312	15544	12714	10233	8396	6794	5433	4234	3191
0.4	23048	20785	17974	15206	12376	9895	8058	6456	5095	3896	2853
0.5	22710	20447	17636	14868	12038	9557	7720	6118	4757	3558	2515
0.6	22372	20109	17298	14530	11700	9219	7382	5780	4419	3220	2177
0.7	22034	19771	16960	14192	11362	8881	7044	5442	4081	2882	1839
0.8	21696	19433	16622	13854	11024	8543	6706	5104	3743	2544	1501
0.9	21358	19095	16284	13516	10686	8205	6368	4766	3405	2206	1163
1.0	21020	18757	15946	13178	10348	7867	6030	4428	3067	1868	825
1.1	20682	18419	15608	12840	10010	7529	5692	4090	2729	1530	487
1.2	20344	18081	15270	12502	9672	7191	5354	3752	2391	1192	149
1.3	20006	17743	14932	12164	9334	6853	5016	3414	2053	854	
1.4	19668	17405	14594	11826	8996	6515	4678	3076	1715	516	
1.5	19330	17067	14256	11488	8658	6177	4340	2738	1377	178	
1.6	18992	16729	13918	11150	8320	5839	4002	2400	1039		
1.7	18654	16391	13580	10812	7982	5501	3664	2062	701		
1.8	18316	16053	13242	10474	7644	5163	3326	1724	363		
1.9	17978	15715	12904	10136	7306	4825	2988	1386	25		
2.0	17640	15377	12566	9798	6968	4487	2650	1048			

ENGINE No. 605 to 609.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	24338	22075	19274	16495	13665	11183	9346	7743	6382	5182	4138
0.1	24004	21741	18940	16161	13331	10849	9012	7409	6048	4848	3804
0.2	23670	21407	18606	15827	12997	10515	8678	7075	5714	4514	3470
0.3	23336	21073	18272	15493	12663	10181	8344	6741	5380	4180	3136
0.4	23002	20739	17938	15159	12329	9847	8010	6407	5046	3846	2802
0.5	22668	20405	17604	14825	11995	9513	7676	6073	4712	3512	2468
0.6	22334	20071	17270	14491	11661	9179	7342	5739	4378	3178	2134
0.7	22000	19737	16936	14157	11327	8845	7008	5405	4044	2844	1800
0.8	21666	19403	16602	13823	10993	8511	6674	5071	3710	2510	1466
0.9	21332	19069	16268	13489	10659	8177	6340	4737	3376	2176	1132
1.0	20998	18735	15934	13155	10325	7843	6006	4403	3042	1842	798
1.1	20664	18401	15600	12821	9991	7509	5672	4067	2708	1508	464
1.2	20330	18067	15266	12487	9657	7175	5338	3735	2374	1174	130
1.3	19996	17733	14932	12153	9323	6841	5004	3401	2040	840	
1.4	19662	17399	14598	11819	8989	6507	4670	3067	1706	506	
1.5	19328	17065	14264	11485	8655	6173	4336	2733	1372	172	
1.6	18994	16731	13930	11151	8321	5839	4002	2399	1038		
1.7	18660	16397	13596	10817	7987	5505	3668	2065	704		
1.8	18326	16063	13262	10483	7653	5171	3334	1731	370		
1.9	17992	15729	12928	10149	7319	4837	3000	1397	36		
2.0	17658	15395	12594	9815	6985	4503	2666	1063			

ENGINE No. 610 TO 619.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
	10	15	20	25	30	35	40	45	50	55	60
0.0	27600	24860	21746	18533	15302	12650	10583	8823	7348	6031	4881
0.1	27246	24506	21392	18179	14948	12296	10229	8469	6994	5677	4527
0.2	26892	24152	21038	17825	14594	11942	9875	8115	6640	5323	4173
0.3	26538	23798	20684	17471	14240	11588	9521	7761	6286	4969	3819
0.4	26184	23444	20330	17117	13886	11234	9167	7407	5932	4615	3465
0.5	25830	23090	19976	16763	13532	10880	8813	7053	5578	4261	3111
0.6	25476	22736	19622	16409	13178	10526	8459	6699	5224	3907	2757
0.7	25122	22382	19268	16055	12824	10172	8105	6345	4870	3553	2403
0.8	24768	22028	18914	15701	12470	9818	7751	5991	4516	3199	2049
0.9	24414	21674	18560	15347	12116	9464	7397	5637	4162	2845	1695
1.0	24060	21320	18206	14993	11762	9110	7043	5283	3808	2491	1341
1.1	23706	20966	17852	14639	11408	8756	6689	4929	3454	2137	987
1.2	23352	20612	17498	14285	11054	8402	6335	4575	3100	1783	633
1.3	22998	20258	17144	13931	10700	8048	5981	4221	2746	1429	279
1.4	22644	19904	16790	13577	10346	7694	5627	3867	2392	1075	
1.5	22290	19550	16436	13223	9992	7340	5273	3513	2038	721	
1.6	21936	19196	16082	12869	9638	6986	4919	3159	1684	367	
1.7	21582	18842	15728	12515	9284	6632	4565	2805	1330	13	
1.8	21228	18488	15374	12161	8930	6278	4211	2451	976		
1.9	20874	18134	15020	11807	8576	5924	3857	2097	622		
2.0	20520	17780	14666	11453	8222	5570	3503	1743	268		

TABLE VII Showing Draw Bar Pull

ENGINE No. 620 TO 623, 634 TO 668.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	27577	24833	21717	18500	15262	12606	10554	8761	7280	5954	4803
0.1	27195	24451	21335	18118	14880	12224	10172	8379	6898	5572	4421
0.2	26813	24069	20953	17736	14498	11842	9790	7997	6516	5190	4039
0.3	26431	23687	20571	17354	14116	11460	9408	7615	6134	4808	3657
0.4	26049	23305	20189	16972	13734	11078	9026	7233	5752	4426	3275
0.5	25667	22923	19807	16590	13352	10696	8644	6851	5370	4044	2893
0.6	25285	22541	19425	16208	12970	10314	8262	6469	4988	3662	2511
0.7	24903	22159	19043	15826	12588	9932	7880	6087	4606	3280	2129
0.8	24521	21777	18661	15444	12206	9550	7498	5705	4224	2898	1747
0.9	24149	21395	18279	15062	11824	9168	7116	5323	3842	2516	1365
1.0	23757	21013	17897	14680	11442	8786	6734	4941	3460	2134	983
1.1	23375	20631	17515	14298	11060	8404	6352	4559	3078	1752	601
1.2	22993	20249	17133	13916	10678	8022	5970	4177	2696	1370	219
1.3	22611	19867	16751	13534	10296	7640	5588	3795	2314	988	
1.4	22239	19485	16369	13152	9914	7258	5206	3413	1932	606	
1.5	21847	19103	15987	12770	9532	6876	4824	3031	1550	224	
1.6	21465	18721	15605	12388	9150	6494	4442	2649	1168		
1.7	21083	18339	15223	12006	8768	6112	4060	2267	786		
1.8	20701	17957	14841	11624	8386	5730	3678	1885	404		
1.9	20329	17575	14459	11242	8004	5348	3296	1503	22		
2.0	19937	17193	14077	10860	7622	4966	2914	1121			

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

ENGINE No. 624 To 628.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	26348	24588	21722	19935	16117	13311	11229	9426	7945	6559	5330
0.1	25968	24208	21342	19555	15737	12931	10849	9046	7565	6179	4950
0.2	25588	23828	20962	19175	15357	12551	10469	8666	7185	5799	4570
0.3	25208	23448	20582	18795	14977	12171	10089	8286	6805	5419	4190
0.4	24828	23068	20202	18415	14597	11791	9709	7906	6425	5039	3810
0.5	24448	22688	19822	18035	14217	11411	9329	7526	6045	4659	3430
0.6	24068	22308	19442	17655	13837	11031	8949	7146	5665	4279	3050
0.7	23688	21928	19062	17275	13457	10651	8569	6766	5285	3899	2670
0.8	23308	21548	18682	16895	13077	10271	8189	6386	4905	3519	2290
0.9	22928	21168	18302	16515	12697	9891	7809	6006	4525	3139	1910
1.0	22548	20778	17922	16135	12317	9511	7429	5626	4145	2759	1530
1.1	22168	20408	17542	15755	11937	9131	7049	5246	3765	2379	1150
1.2	21788	20028	17162	15375	11557	8751	6669	4866	3385	1999	770
1.3	21408	19648	16782	14995	11177	8371	6289	4486	3005	1619	390
1.4	21028	19268	16402	14615	10797	7991	5909	4106	2625	1239	10
1.5	20648	18888	16022	14235	10417	7611	5529	3726	2245	859	
1.6	20268	18508	15642	13855	10037	7231	5149	3346	1865	479	
1.7	19888	18128	15262	13475	9657	6851	4769	2966	1485	99	
1.8	19508	17748	14882	13095	9277	6471	4389	2586	1105		
1.9	19128	17368	14502	12715	8897	6091	4009	2206	725		
2.0	18748	16988	14122	12335	8517	5711	3629	1826	345		

TABLE VII Showing Draw Bar Pull of Frisco Locomotives

SHEET 85

ENGINE No. 629 TO 633

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
	10	15	20	25	30	35	40	45	50	55	60
0.0	26264	24505	21637	18849	16030	13224	11141	9337	7814	6467	5238
0.1	25870	24111	21243	18455	15636	12830	10747	8943	7420	6073	4844
0.2	25476	23717	20849	18061	15242	12436	10353	8549	7026	5679	4450
0.3	25082	23323	20455	17667	14848	12042	9959	8155	6632	5285	4056
0.4	24688	22929	20061	17273	14454	11648	9565	7761	6238	4891	3662
0.5	24294	22535	19667	16879	14060	11254	9171	7367	5844	4497	3268
0.6	23900	22141	19273	16485	13666	10860	8777	6973	5450	4103	2874
0.7	23506	21747	18879	16091	13272	10466	8383	6579	5056	3709	2480
0.8	23112	21353	18485	15697	12878	10072	7989	6185	4662	3315	2086
0.9	22718	20959	18091	15303	12484	9678	7595	5791	4268	2921	1692
1.0	22324	20565	17697	14909	12090	9284	7201	5397	3874	2527	1298
1.1	21930	20171	17303	14515	11696	8890	6807	5003	3480	2133	904
1.2	21536	19777	16909	14121	11302	8496	6413	4609	3086	1739	510
1.3	21142	19383	16515	13727	10908	8102	6019	4215	2692	1345	116
1.4	20748	18989	16121	13333	10514	7708	5625	3821	2298	951	
1.5	20354	18595	15727	12939	10120	7314	5231	3427	1904	557	
1.6	19960	18201	15333	12545	9726	6920	4837	3033	1510	163	
1.7	19566	17807	14939	12151	9332	6526	4443	2639	1116		
1.8	19172	17413	14545	11757	8938	6132	4049	2245	722		
1.9	18778	17019	14151	11363	8544	5738	3655	1851	328		
2.0	18384	16625	13757	10969	8150	5344	3261	1457			

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET 84

ENGINE No. 695 to 699, 705 to 724.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	31263	27471	23583	19705	15902	13211	10987	9091	7503	6124	4953
0.1	30855	27063	23175	19297	15494	12803	10579	8683	7095	5716	4545
0.2	30447	26655	22767	18889	15086	12395	10171	8275	6687	5308	4137
0.3	30039	26247	22359	18481	14678	11987	9763	7867	6279	4900	3729
0.4	29631	25839	21951	18073	14270	11579	9355	7459	5871	4492	3321
0.5	29223	25431	21543	17665	13862	11171	8947	7051	5463	4084	2913
0.6	28815	25023	21135	17257	13454	10763	8539	6643	5055	3676	2505
0.7	28407	24615	20727	16849	13046	10355	8131	6235	4647	3268	2097
0.8	27999	24207	20319	16441	12638	9947	7723	5827	4239	2860	1689
0.9	27591	23799	19911	16033	12230	9539	7315	5419	3831	2452	1281
1.0	27183	23391	19503	15625	11822	9131	6907	5011	3423	2044	873
1.1	26775	22983	19095	15217	11414	8723	6499	4603	3015	1636	465
1.2	26367	22575	18687	14809	11006	8315	6090	4195	2607	1228	57
1.3	25959	22167	18279	14401	10598	7907	5683	3787	2199	820	
1.4	25551	21759	17871	13995	10190	7499	5275	3379	1791	412	
1.5	25143	21351	17463	13585	9782	7091	4867	2971	1383		
1.6	24735	20943	17055	13177	9374	6683	4459	2563	975		
1.7	24327	20535	16647	12769	8966	6275	4051	2155	567		
1.8	23919	20127	16239	12361	8558	5867	3643	1747	159		
1.9	23511	19719	15831	11953	8150	5459	3235	1339			
2.0	23103	19311	15423	11545	7742	5051	2827	931			

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET-85.

ENGINE No. 700 to 704.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
	10	15	20	25	30	35	40	45	50	55	60
0.0	27247	22330	19751	16402	13466	10858	8667	6641	4377	3294	1889
0.1	26911	21994	19415	16066	13130	10522	8331	6305	4041	2958	1553
0.2	26575	21658	19079	15730	12794	10186	7995	5969	3705	2622	1217
0.3	26239	21322	18743	15394	12458	9850	7659	5633	3369	2286	881
0.4	25903	20986	18407	15058	12122	9514	7323	5297	3033	1950	545
0.5	25567	20650	18071	14722	11786	9178	6987	4961	2697	1614	209
0.6	25231	20314	17735	14386	11450	8842	6651	4625	2361	1278	
0.7	24895	19978	17399	14050	11114	8506	6315	4289	2025	942	
0.8	24559	19642	17063	13714	10778	8170	5979	3953	1689	606	
0.9	24223	19306	16727	13378	10442	7834	5643	3617	1353	270	
1.0	23887	18970	16391	13042	10106	7498	5307	3281	1017		
1.1	23551	18634	16055	12706	9770	7162	4971	2945	681		
1.2	23215	18298	15719	12370	9434	6826	4635	2609	345		
1.3	22879	17962	15383	12034	9098	6490	4299	2273	9		
1.4	22543	17626	15047	11698	8762	6154	3963	1937			
1.5	22207	17290	14711	11362	8426	5818	3627	1601			
1.6	21871	16954	14375	11026	8090	5482	3291	1265			
1.7	21535	16618	14039	10690	7754	5146	2955	929			
1.8	21199	16282	13703	10354	7418	4810	2619	593			
1.9	20863	15946	13367	10018	7082	4474	2283	257			
2.0	20527	15610	13031	9682	6746	4138	1947				

ENGINE No. 727 to 741.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	31315	27525	23637	19759	15959	13273	11049	9155	7560	6194	5027
0.1	30919	27129	23241	19363	15563	12877	10653	8759	7164	5798	4631
0.2	30523	26733	22845	18967	15167	12481	10257	8363	6768	5402	4235
0.3	30127	26337	22449	18571	14771	12085	9861	7967	6372	5006	3839
0.4	29731	25941	22053	18175	14375	11689	9465	7571	5976	4610	3443
0.5	29335	25545	21657	17779	13979	11293	9069	7175	5580	4214	3047
0.6	28939	25149	21261	17383	13583	10897	8673	6779	5184	3818	2651
0.7	28543	24153	20865	16987	13187	10501	8277	6383	4788	3422	2255
0.8	28147	24357	20469	16591	12791	10105	7881	5987	4392	3026	1859
0.9	27751	23961	20073	16195	12395	9709	7485	5591	3996	2630	1463
1.0	27335	23565	19677	15799	11999	9313	7089	5195	3600	2234	1067
1.1	26959	23169	19281	15403	11603	8917	6693	4799	3204	1838	671
1.2	26563	22773	18885	15007	11207	8521	6297	4403	2808	1442	275
1.3	26167	22377	18489	14611	10811	8125	5901	4007	2412	1046	
1.4	25771	21981	18093	14215	10415	7729	5505	3611	2016	650	
1.5	25375	21585	17697	13819	10019	7333	5109	3215	1620	254	
1.6	24979	21189	17301	13423	9623	6937	4713	2819	1224		
1.7	24583	20793	16905	13027	9227	6541	4317	2423	828		
1.8	24187	20397	16509	12631	8831	6145	3921	2027	432		
1.9	23791	20001	16113	12235	8435	5749	3525	1631	36		
2.0	23395	19605	15717	11839	8039	5353	3129	1235			

ENGINE No. 743 TO 746, 748, 752, 753, 754, 756 TO 759, 763 TO 770, 772, 773, 774.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	30217	25746	21467	17469	14194	11239	9029	6399	4534	2621	1862
0.1	29817	25346	21067	17069	13794	10839	8629	5999	4134	2221	1462
0.2	29417	24946	20667	16669	13394	10439	8229	5599	3734	1821	1062
0.3	29017	24546	20267	16269	12994	10039	7829	5199	3334	1421	662
0.4	28617	24146	19867	15869	12594	9639	7429	4799	2934	1021	262
0.5	28217	23746	19467	15469	12194	9239	7029	4399	2534	621	
0.6	27817	23346	19067	15069	11794	8839	6629	3999	2134	221	
0.7	27417	22946	18667	14669	11394	8439	6229	3599	1734		
0.8	27017	22546	18267	14269	10994	8039	5829	3199	1334		
0.9	26617	22146	17867	13869	10594	7639	5429	2799	934		
1.0	26217	21746	17467	13469	10194	7239	5029	2399	534		
1.1	25817	21346	17067	13069	9794	6839	4629	1999	134		
1.2	25417	20946	16667	12669	9394	6439	4229	1599			
1.3	25017	20546	16267	12269	8994	6039	3829	1199			
1.4	24617	20146	15867	11869	8594	5639	3429	799			
1.5	24217	19746	15467	11469	8194	5239	3029	399			
1.6	23817	19346	15067	11069	7794	4839	2629				
1.7	23417	18946	14667	10669	7394	4439	2229				
1.8	23017	18546	14267	10269	6994	4039	1829				
1.9	22617	18146	13867	9869	6594	3639	1429				
2.0	22217	17746	13467	9469	6194	3239	1029				

ENGINE No. 742, 747, 749, 750, 751, 755, 760, 761, 762, 771, 775 to 799.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	31315	27523	23634	19756	15953	13267	11043	9145	7556	6181	5012
0.1	30915	27123	23234	19356	15533	12867	10643	8745	7156	5781	4612
0.2	30515	26723	22834	18956	15153	12467	10243	8345	6756	5381	4212
0.3	30115	26323	22434	18556	14753	12067	9843	7945	6356	4981	3812
0.4	29715	25923	22034	18156	14353	11667	9443	7545	5956	4581	3412
0.5	29315	25523	21634	17756	13953	11267	9043	7145	5556	4181	3012
0.6	28915	25123	21234	17356	13553	10867	8643	6745	5156	3781	2612
0.7	28515	24723	20834	16956	13153	10467	8243	6345	4756	3381	2212
0.8	28115	24323	20434	16556	12753	10067	7843	5945	4356	2981	1812
0.9	27715	23923	20034	16156	12353	9667	7443	5545	3956	2581	1412
1.0	27315	23523	19634	15756	11953	9267	7043	5145	3556	2181	1012
1.1	26915	23123	19234	15356	11553	8867	6643	4745	3156	1781	612
1.2	26515	22723	18834	14956	11153	8467	6243	4345	2756	1381	212
1.3	26115	22323	18434	14556	10753	8067	5843	3945	2356	981	
1.4	25715	21923	18034	14156	10353	7667	5443	3545	1956	581	
1.5	25315	21523	17634	13756	9953	7267	5043	3145	1556	181	
1.6	24915	21123	17234	13356	9553	6867	4643	2745	1156		
1.7	24515	20723	16834	12956	9153	6467	4243	2345	756		
1.8	24115	20323	16434	12556	8753	6067	3843	1945	356		
1.9	23715	19923	16034	12156	8353	5667	3443	1545			
2.0	23315	19523	15634	11756	7953	5267	3043	1145			

ENGINE No. 801 to 818.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL. 10	15	20	25	30	35	40	45	50	55	60
0.0	31282	26990	22664	18303	14787	12189	10034	8270	6807	5531	4364
0.1	30946	26654	22328	17967	14451	11853	9698	7934	6471	5195	4028
0.2	30610	26318	21992	17631	14115	11517	9362	7598	6135	4859	3692
0.3	30274	25982	21656	17295	13779	11181	9026	7262	5799	4523	3356
0.4	29938	25646	21320	16959	13443	10845	8690	6926	5463	4187	3020
0.5	29602	25310	20984	16623	13107	10509	8354	6590	5127	3851	2684
0.6	29266	24974	20648	16287	12771	10173	8018	6254	4791	3515	2348
0.7	28930	24638	20312	15951	12435	9837	7682	5918	4455	3179	2012
0.8	28594	24302	19976	15615	12099	9501	7346	5582	4119	2843	1676
0.9	28258	23966	19640	15279	11763	9165	7010	5246	3783	2507	1340
1.0	27922	23630	19304	14943	11427	8829	6674	4910	3447	2171	1004
1.1	27586	23294	18968	14607	11091	8493	6338	4574	3111	1835	668
1.2	27250	22958	18632	14271	10755	8157	6002	4238	2775	1499	332
1.3	26914	22622	18296	13935	10419	7821	5666	3902	2439	1163	
1.4	26578	22286	17960	13599	10083	7485	5330	3566	2103	827	
1.5	26242	21950	17624	13263	9747	7149	4994	3230	1767	491	
1.6	25906	21614	17288	12927	9411	6813	4658	2894	1431	155	
1.7	25570	21278	16952	12591	9075	6477	4322	2558	1095		
1.8	25234	20942	16616	12255	8739	6141	3986	2222	759		
1.9	24898	20606	16280	11919	8403	5805	3650	1886	423		
2.0	24562	20270	15944	11583	8067	5469	3314	1550	87		

ENGINE No. 819 to 828.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL. 10	15	20	25	30	35	40	45	50	55	60
0.0	33966	29304	24648	19947	16141	13348	11038	9134	7576	6212	4970
0.1	33628	28966	24310	19609	15803	13010	10700	8796	7238	5874	4632
0.2	33290	28628	23972	19271	15465	12672	10362	8458	6900	5536	4294
0.3	32952	28290	23634	18933	15127	12334	10024	8120	6562	5198	3956
0.4	32614	27952	23296	18595	14789	11996	9686	7782	6224	4860	3618
0.5	32276	27614	22958	18257	14451	11658	9348	7444	5886	4522	3280
0.6	31938	27276	22620	17919	14113	11320	9010	7106	5548	4184	2942
0.7	31600	26938	22282	17581	13775	10982	8672	6768	5210	3846	2604
0.8	31262	26600	21944	17243	13437	10644	8334	6430	4872	3508	2266
0.9	30924	26262	21606	16905	13099	10306	7996	6092	4534	3170	1928
1.0	30586	25924	21268	16567	12761	9968	7658	5754	4196	2832	1590
1.1	30248	25586	20930	16229	12423	9630	7320	5416	3858	2494	1252
1.2	29910	25248	20592	15891	12085	9292	6982	5078	3520	2156	914
1.3	29572	24910	20254	15553	11747	8954	6644	4740	3182	1818	576
1.4	29234	24572	19916	15215	11409	8616	6306	4402	2844	1480	238
1.5	28896	24234	19578	14877	11071	8278	5968	4064	2506	1142	
1.6	28558	23896	19240	14539	10733	7940	5630	3726	2168	804	
1.7	28220	23558	18902	14201	10395	7602	5292	3388	1830	466	
1.8	27882	23220	18564	13863	10057	7264	4954	3050	1492	128	
1.9	27544	22882	18226	13525	10719	6926	4616	2712	1154		
2.0	27206	22544	17888	13187	9381	6588	4278	2374	816		

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

ENGINE No. 829 to 833.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL. 10	15	20	25	30	35	40	45	50	55	60
0.0	33980	29317	24660	19958	16142	13358	11047	9142	7582	6218	4975
0.1	33642	28979	24322	19620	15804	13020	10709	8804	7244	5880	4637
0.2	33304	28641	23984	19282	15466	12682	10371	8466	6906	5542	4299
0.3	32966	28303	23646	18944	15128	12344	10033	8128	6568	5204	3961
0.4	32628	27965	23308	18606	14790	12006	9695	7790	6230	4866	3623
0.5	32290	27627	22970	18268	14452	11668	9357	7452	5892	4528	3285
0.6	31952	27289	22632	17930	14114	11330	9019	7114	5554	4190	2947
0.7	31614	26951	22294	17592	13776	10992	8681	6976	5216	3852	2609
0.8	31276	26613	21956	17254	13438	10654	8343	6438	4878	3514	2271
0.9	30938	26275	21618	16916	13100	10316	8005	6100	4540	3176	1933
1.0	30600	25937	21280	16578	12762	9978	7667	5762	4202	2838	1595
1.1	30262	25599	20942	16240	12424	9640	7329	5424	3864	2500	1257
1.2	29924	25261	20604	15902	12086	9302	6991	5086	3526	2162	919
1.3	29586	24923	20266	15564	11748	8964	6653	4948	3188	1824	581
1.4	29248	24585	19928	15226	11410	8626	6315	4410	2850	1486	243
1.5	28910	24247	19590	14888	11072	8288	5977	4072	2512	1148	
1.6	28572	23909	19252	14550	10734	7950	5639	3934	2174	810	
1.7	28234	23571	18914	14212	10396	7612	5301	3396	1836	472	
1.8	27896	23233	18576	13874	10058	7274	4963	3058	1498	134	
1.9	27558	22895	18238	13536	9720	6936	4625	2920	1160		
2.0	27220	22557	17900	13198	9382	6598	4287	2382	822		

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET-92.

ENGINE No. 834-835.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	33399	28105	22773	17700	14364	11713	9544	7774	6289	4865	3491
0.1	33033	27739	22407	17334	13998	11347	9178	7408	5923	4499	3125
0.2	32667	27373	22041	16968	13632	10981	8812	7042	5557	4133	2759
0.3	32301	27007	21675	16602	13266	10615	8446	6676	5191	3767	2393
0.4	31935	26641	21309	16236	12900	10249	8080	6310	4825	3401	2027
0.5	31569	26275	20943	15870	12534	9883	7714	5944	4459	3035	1661
0.6	31203	25909	20577	15504	12168	9517	7348	5578	4093	2669	1295
0.7	30837	25543	20211	15138	11802	9151	6982	5212	3727	2303	829
0.8	30471	25177	19845	14772	11436	8785	6616	4846	3361	1937	463
0.9	30105	24811	19479	14406	11070	8419	6250	4480	2995	1571	97
1.0	29739	24445	19113	14040	10704	8053	5884	4114	2629	1205	
1.1	29373	24079	18747	13674	10338	7687	5518	3748	2263	839	
1.2	29007	23713	18381	13308	9972	7321	5152	3382	1897	473	
1.3	28641	23347	18015	12942	9606	6955	4786	3016	1531	107	
1.4	28275	22981	17649	12576	9240	6589	4420	2650	1165		
1.5	27909	22615	17283	12210	8874	6223	4054	2284	799		
1.6	27543	22249	16917	11844	8508	5857	3688	1918	433		
1.7	27177	21883	16551	11478	8142	5491	3322	1552	67		
1.8	26811	21517	16185	11112	7776	5125	2956	1186			
1.9	26445	21151	15819	10746	7410	4759	2590	820			
2.0	26079	20785	15453	10380	7044	4393	2224	454			

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

ENGINE No. 950 to 955

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	32965	28254	23480	18688	15105	12350	10216	8352	6881	5572	4284
0.1	32627	27916	23142	18350	14767	12012	9878	8014	6543	5234	3946
0.2	32289	27578	22804	18012	14429	11674	9540	7676	6205	4896	3608
0.3	31951	27240	22466	17674	14091	11336	9202	7338	5867	4558	3270
0.4	31613	26902	22128	17336	13753	10998	8864	7000	5529	4220	2932
0.5	31275	26564	21790	16998	13415	10660	8526	6662	5191	3882	2594
0.6	30937	26226	21452	16660	13077	10322	8188	6324	4853	3544	2256
0.7	30599	25888	21114	16322	12739	9984	7850	5986	4515	3206	1918
0.8	30261	25550	20776	15984	12401	9646	7512	5648	4177	2868	1580
0.9	29923	25212	20438	15646	12063	9308	7174	5310	3839	2536	1242
1.0	29585	24874	20100	15308	11725	8970	6836	4972	3501	2192	904
1.1	29247	24536	19762	14970	11387	8632	6498	4634	3163	1854	566
1.2	28909	24198	19424	14632	11049	8294	6160	4296	2825	1516	228
1.3	28571	23860	19086	14294	10711	7956	5822	3958	2487	1178	
1.4	28233	23522	18748	13956	10373	7618	5484	3620	2149	840	
1.5	27895	23184	18410	13618	10035	7280	5146	3282	1811	502	
1.6	27557	22846	18072	13280	9697	6942	4808	2944	1473	164	
1.7	27219	22508	17734	12942	9359	6604	4470	2606	1135		
1.8	26881	22170	17396	12604	9021	6266	4132	2268	797		
1.9	26543	21832	17058	12266	8683	5928	3794	1930	459		
2.0	26205	21494	16720	11928	8345	5590	3456	1592	121		

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

Sheet 94

ENGINE No. 956 to 965.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	33827	29163	24502	19797	15988	13190	10888	8960	7394	6025	4781
0.1	33465	28801	24140	19435	15626	12828	10526	8598	7032	5663	4419
0.2	33103	28439	23778	19073	15264	12466	10164	8236	6670	5301	4057
0.3	32741	28077	23416	18711	14902	12104	9802	7874	6308	4939	3695
0.4	32379	27715	23054	18349	14540	11742	9440	7512	5946	4577	3333
0.5	32017	27353	22692	17987	14178	11380	9078	7150	5584	4215	2971
0.6	31655	26991	22330	17625	13816	11018	8716	6788	5222	3853	2609
0.7	31293	26629	21968	17263	13454	10656	8354	6426	4860	3491	2247
0.8	30931	26267	21606	16901	13092	10294	7992	6064	4498	3129	1885
0.9	30569	25905	21244	16539	12730	9932	7630	5702	4136	2767	1523
1.0	30207	25543	20882	16177	12368	9570	7268	5340	3774	2405	1161
1.1	29845	25181	20520	15815	12006	9208	6906	4978	3412	2043	799
1.2	29483	24819	20158	15453	11644	8846	6544	4616	3050	1681	437
1.3	29121	24457	19796	15091	11282	8484	6182	4254	2688	1319	75
1.4	28759	24095	19434	14729	10920	8122	5820	3892	2326	957	
1.5	28397	23733	19072	14367	10558	7760	5458	3530	1964	595	
1.6	28035	23371	18710	14005	10196	7398	5096	3168	1602	233	
1.7	27673	23009	18348	13643	9834	7036	4734	2806	1240		
1.8	27311	22647	17986	13281	9472	6674	4372	2444	878		
1.9	26949	22285	17624	12919	9110	6312	4010	2082	516		
2.0	26587	21923	17262	12557	8748	5950	3648	1720	154		

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET-95.

ENGINE No. 970 TO 989.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	34727	29752	24720	19670	15887	12998	10777	8781	7226	5861	4491
0.1	34343	29368	24336	19286	15503	12614	10393	8397	6842	5477	4107
0.2	33959	28984	23952	18902	15119	12230	10009	8013	6458	5093	3723
0.3	33575	28600	23568	18518	14735	11846	9625	7629	6074	4709	3339
0.4	33191	28216	23184	18134	14351	11462	9241	7245	5690	4325	2955
0.5	32807	27832	22800	17750	13967	11078	8857	6861	5306	3941	2571
0.6	32423	27448	22416	17366	13583	10694	8473	6477	4922	3557	2187
0.7	32039	27064	22032	16982	13199	10310	8089	6093	4538	3173	1803
0.8	31655	26680	21648	16598	12815	9926	7705	5709	4154	2789	1419
0.9	31271	26296	21264	16214	12431	9542	7321	5325	3770	2405	1035
1.0	30887	25912	20880	15830	12047	9158	6937	4941	3386	2021	651
1.1	30503	25528	20496	15446	11663	8774	6553	4557	3002	1637	267
1.2	30119	25144	20112	15062	11279	8390	6169	4173	2618	1253	
1.3	29735	24760	19728	14678	10895	8006	5785	3789	2234	869	
1.4	29351	24376	19344	14294	10511	7622	5401	3405	1850	485	
1.5	28967	23992	18960	13910	10127	7238	5017	3021	1466	101	
1.6	28583	23608	18576	13526	9743	6854	4633	2637	1082		
1.7	28199	23224	18192	13142	9359	6470	4249	2253	698		
1.8	27815	22840	17808	12758	8975	6086	3865	1869	314		
1.9	27431	22456	17424	12374	8591	5702	3481	1485			
2.0	27047	22072	17040	11990	8207	5318	3097	1101			

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET-96

ENGINE No. 1000 to 1009.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	23674	22062	19445	16887	14314	11732	9814	8136	6723	5465	4311
0.1	23270	21658	19041	16483	13910	11328	9410	7732	6319	5061	3907
0.2	22866	21254	18637	16079	13506	10924	9006	7328	5915	4657	3503
0.3	22462	20850	18233	15675	13102	10520	8602	6924	5511	4253	3099
0.4	22058	20446	17829	15271	12698	10116	8198	6520	5107	3849	2695
0.5	21654	20042	17425	14867	12294	9712	7794	6116	4703	3445	2291
0.6	21250	19638	17021	14463	11890	9308	7390	5712	4299	3041	1887
0.7	20846	19234	16617	14059	11486	8904	6986	5308	3895	2637	1483
0.8	20442	18830	16213	13655	11082	8500	6582	4904	3491	2233	1079
0.9	20038	18426	15809	13251	10678	8096	6178	4500	3087	1829	675
1.0	19634	18022	15405	12847	10274	7692	5774	4096	2683	1425	271
1.1	19230	17618	15001	12443	9870	7288	5370	3692	2279	1021	
1.2	18826	17214	14597	12039	9466	6884	4966	3288	1875	617	
1.3	18422	16810	14193	11635	9062	6480	4562	2884	1471	213	
1.4	18018	16406	13789	11231	8658	6076	4158	2480	1067		
1.5	17614	16002	13385	10827	8254	5672	3754	2076	663		
1.6	17210	15598	12981	10423	7850	5268	3350	1672	259		
1.7	16806	15194	12577	10019	7446	4864	2946	1268			
1.8	16402	14790	12173	9615	[illegible]	4460	2542	864			
1.9	15998	14386	11769	[illegible]	[illegible]	4056	2138	460			
2.0	15594	13982			[illegible]	3652	1734	56			

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET-97.

ENGINE No. 1010 TO 1014.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	23723	22110	19492	16933	14359	11777	9864	8175	6761	5502	4346
0.1	23317	21704	19086	16527	13953	11371	9458	7769	6355	5096	3940
0.2	22911	21298	18680	16121	13547	10965	9052	7363	5949	4690	3534
0.3	22505	20892	18274	15715	13141	10559	8646	6957	5543	4284	3128
0.4	22099	20486	17868	15309	12735	10153	8240	6551	5137	3878	2722
0.5	21693	20080	17462	14903	12329	9747	7834	6145	4731	3472	2316
0.6	21287	19674	17056	14497	11923	9341	7428	5739	4325	3066	1910
0.7	20881	19268	16650	14091	11517	8935	7022	5333	3919	2660	1504
0.8	20475	18862	16244	13685	11111	8529	6616	4927	3513	2254	1098
0.9	20069	18456	15838	13279	10705	8123	6210	4521	3107	1848	692
1.0	19663	18050	15432	12873	10299	7717	5804	4115	2701	1442	286
1.1	19257	17644	15026	12467	9893	7311	5398	3709	2295	1036	
1.2	18851	17238	14620	12061	9487	6905	4992	3303	1889	630	
1.3	18445	16832	14214	11655	9081	6499	4586	2897	1483	224	
1.4	18039	16426	13808	11249	8675	6093	4180	2491	1077		
1.5	17633	16020	13402	10843	8269	5687	3774	2085	671		
1.6	17227	15614	12996	10437	7863	5281	3368	1679	265		
1.7	16821	15208	12590	10031	7457	4875	2962	1273			
1.8	16415	14802	12184	9625	7051	4469	2556	867			
1.9	16009	14396	11778	9219	6645	4063	2150	461			
2.0	15603	13990	11372	8813	6239	3657	1744	55			

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET - 98.

ENGINE No. 1015 TO 1039.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	35097	31907	27931	23975	19985	16488	13976	11697	9897	8169	6735
0.1	34629	31439	27463	23507	19517	16020	13508	11229	9429	7701	6267
0.2	34161	30971	26995	23039	19049	15552	13040	10761	8961	7233	5799
0.3	33693	30503	26527	22571	18581	15084	12572	10293	8493	6765	5331
0.4	33225	30035	26059	22103	18113	14616	12104	9825	8025	6297	4863
0.5	32757	29567	25591	21635	17645	14148	11636	9357	7557	5829	4395
0.6	32289	29099	25123	21167	17177	13680	11168	8889	7089	5361	3927
0.7	31821	28631	24655	20699	16709	13212	10700	8421	6621	4893	3459
0.8	31353	28163	24187	20231	16241	12744	10232	7953	6153	4425	2991
0.9	30885	27695	23719	19763	15773	12276	9764	7485	5685	3957	2523
1.0	30417	27227	23251	19295	15305	11808	9296	7017	5217	3489	2055
1.1	29949	26759	22783	18827	14837	11340	8828	6549	4749	3021	1587
1.2	29481	26291	22315	18359	14369	10872	8360	6081	4281	2553	1119
1.3	29013	25823	21847	17891	13901	10404	7892	5613	3813	2085	651
1.4	28545	25355	21379	17423	13433	9936	7424	5145	3345	1617	183
1.5	28077	24887	20911	16955	12965	9468	6956	4677	2877	1149	
1.6	27609	24419	20443	16487	12497	9000	6488	4209	2409	681	
1.7	27141	23951	19975	16019	12029	8532	6020	3741	1941	213	
1.8	26673	23483	19507	15551	11561	8064	5552	3273	1473		
1.9	26205	23015	19039	15083	11093	7596	5084	2805	1005		
2.0	25737	22547	18571	14615	10625	7128	4616	2337	537		

TABLE VII Showing Draw Bar Pull of [illegible] Locomotives

SHEET-99

ENGINE No. 1100 to 1111

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
	10	15	20	25	30	35	40	45	50	55	60
0.0	26247	24486	21618	18831	16011	13205	11120	9319	7793	6450	5219
0.1	25855	24094	21226	18439	15619	12813	10728	8927	7401	6058	4827
0.2	25463	23702	20834	18047	15227	12421	10336	8535	7009	5666	4435
0.3	25071	23310	20442	17655	14835	12029	9944	8143	6617	5274	4043
0.4	24679	22918	20050	17263	14443	11637	9552	7751	6225	4882	3651
0.5	24287	22526	19658	16871	14051	11245	9160	7359	5833	4490	3259
0.6	23895	22134	19266	16479	13659	10853	8768	6967	5441	4098	2867
0.7	23703	21742	18874	16087	13267	10461	8376	6575	5049	3706	2475
0.8	23111	21350	18482	15695	12875	10069	7984	6183	4657	3314	2083
0.9	22719	20958	18090	15303	12483	9677	7592	5791	4265	2922	1691
1.0	22327	20566	17698	14911	12091	9285	7200	5399	3873	2530	1299
1.1	21935	20174	17306	14519	11699	8893	6808	5007	3481	2138	907
1.2	21543	19782	16914	14127	11307	8501	6416	4615	3089	1746	515
1.3	21151	19390	16522	13735	10915	8109	6024	4223	2697	1354	123
1.4	20759	18998	16130	13343	10523	7717	5632	3831	2305	962	
1.5	20367	18606	15738	12951	10131	7325	5240	3439	1913	570	
1.6	19975	18214	15346	12559	9739	6933	4848	3047	1521	178	
1.7	19583	17822	14954	12167	9347	6541	4456	2655	1129		
1.8	19191	17430	14562	11775	8955	6149	4064	2263	737		
1.9	18799	17038	14170	11383	8563	5757	3672	1871	345		
2.0	18407	16646	13778	10991	8171	5365	3280	1479			

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET- 100.

ENGINE No. 1200 TO 1225.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL.										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	39168	33261	27384	21612	17961	14337	11869	9639	7975	6394	4832
0.1	38734	32827	26950	21178	17527	13903	11435	9205	7541	5960	4398
0.2	38300	32393	26516	20744	17093	13469	11001	8771	7107	5526	3964
0.3	37866	31959	26082	20310	16659	13035	10567	8337	6673	5092	3530
0.4	37432	31525	25648	19876	16225	12601	10133	7903	6239	4658	3096
0.5	36998	31091	25214	19442	15791	12167	9699	7469	5805	4224	2662
0.6	36564	30657	24780	19008	15357	11733	9265	7035	5371	3790	2228
0.7	36130	30223	24346	18574	14923	11299	8831	6601	4937	3356	1794
0.8	35696	29789	23912	18140	14489	10865	8397	6167	4503	2922	1360
0.9	35262	29355	23478	17706	14055	10431	7963	5733	4069	2488	926
1.0	34828	28921	23044	17272	13621	9997	7529	5299	3635	2054	492
1.1	34394	28487	22610	16838	13187	9563	7095	4865	3201	1620	58
1.2	33960	28053	22176	16404	12753	9129	6661	4431	2767	1186	
1.3	33526	27619	21742	15970	12319	8695	6227	3997	2333	752	
1.4	33092	27185	21308	15536	11885	8261	5793	3563	1899	318	
1.5	32658	26751	20874	15102	11451	7827	5359	3129	1465		
1.6	32224	26317	20440	14668	11017	7393	4925	2695	1031		
1.7	31790	25883	20006	14234	10583	6959	4491	2261	597		
1.8	31356	25449	19572	13800	10149	6525	4057	1827	163		
1.9	30922	25015	19138	13366	9715	6091	3623	1393			
2.0	30488	24581	18704	12932	9281	5657	3189	959			

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET-101.

ENGINE No. 1226 to 1265.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	39068	33161	27284	21512	17861	14237	11769	9539	7875	6294	4732
0.1	38626	32719	26842	21070	17419	13795	11327	9097	7433	5852	4290
0.2	38184	32277	26400	20628	16977	13353	10885	8655	6991	5410	3848
0.3	37742	31835	25958	20186	16535	12911	10443	8213	6549	4968	3406
0.4	37300	31393	25516	19744	16093	12469	10001	7771	6107	4526	2964
0.5	36858	30951	25074	19302	15651	12027	9559	7329	5665	4084	2522
0.6	36416	30509	24632	18860	15209	11585	9117	6887	5223	3642	2080
0.7	35974	30067	24190	18418	14767	11143	8675	6445	4181	3200	1638
0.8	35532	29625	23748	17976	14325	10701	8233	6003	4339	2758	1196
0.9	35090	29183	23306	17534	13883	10259	7791	5561	3897	2316	754
1.0	34648	28741	22864	17092	13441	9817	7349	5119	3455	1874	312
1.1	34206	28299	22422	16650	12999	9375	6907	4677	3013	1432	
1.2	33764	27857	21980	16208	12557	8933	6465	4235	2571	990	
1.3	33322	27415	21538	15766	12115	8491	6023	3793	2129	548	
1.4	32880	26973	21096	15324	11673	8049	5581	3351	1687	106	
1.5	32438	26531	20654	14882	11231	7607	5139	2909	1245		
1.6	31996	26089	20212	14440	10789	7165	4697	2467	803		
1.7	31554	25647	19770	13998	10347	6723	4255	2025	361		
1.8	31112	25205	19328	13556	9905	6281	3813	1583			
1.9	30670	24763	18886	13114	9463	5839	3371	1141			
2.0	30228	24321	18444	12672	9021	5397	2929	699			

TABLE VII Showing Draw Bar Pull of Frisco Locomotives

SHEET- 102

ENGINE No. 1266 TO 1280

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	39578	34372	29161	23664	19175	15896	13217	10958	9059	7377	6057
0.1	39132	33926	28715	23218	18729	15450	12771	10512	8613	6931	5611
0.2	38686	33480	28269	22772	18283	15004	12325	10066	8167	6485	5165
0.3	38240	33034	27823	22326	17837	14558	11879	9620	7721	6039	4719
0.4	37794	32588	27377	21880	17391	14112	11433	9174	7275	5593	4273
0.5	37348	32142	26931	21434	16945	13666	10987	8728	6829	5147	3827
0.6	36902	31696	26485	20988	16499	13220	10541	8282	6383	4701	3381
0.7	36456	31250	26039	20542	16053	12774	10095	7836	5937	4255	2935
0.8	36010	30804	25593	20096	15607	12338	9649	7390	5491	3809	2489
0.9	35564	30358	25147	19650	15161	11892	9203	6944	5045	3363	2043
1.0	35118	29912	24701	19204	14715	11446	8757	6498	4599	2917	1597
1.1	34672	29466	24255	18758	14269	11000	8311	6052	4153	2471	1151
1.2	34226	29020	23809	18312	13823	10554	7865	5606	3707	2025	705
1.3	33780	28574	23363	17866	13377	10108	7419	5160	3261	1579	259
1.4	33334	28128	22917	17420	12931	9652	6973	4714	2815	1133	
1.5	32888	27682	22471	16974	12485	9206	6527	4268	2369	687	
1.6	32442	27236	22025	16528	12039	8760	6081	3822	1923	241	
1.7	31996	26790	21579	16082	11593	8314	5635	3376	1477		
1.8	31550	26344	21133	15636	11147	7868	5189	2930	1031		
1.9	31104	25898	20687	15190	10701	7422	4743	2484	585		
2.0	30658	25452	20241	14744	10255	6976	4297	2038	139		

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET-103.

ENGINE No. 1281 to 1292.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	41743	36233	30785	25000	20261	16821	14010	11563	9621	7978	6491
0.1	41179	35669	30221	24436	19697	16257	13446	10999	9057	7414	5927
0.2	40615	35105	29657	23872	19133	15693	12882	10435	8493	6850	5363
0.3	40051	34541	29093	23308	18569	15129	12318	9871	7929	6286	4799
0.4	39487	33977	28529	22744	18005	14565	11754	9307	7365	5722	4235
0.5	38923	33413	27965	22180	17441	14001	11190	8743	6801	5158	3671
0.6	38359	32849	27401	21616	16877	13437	10626	8179	6237	4594	3107
0.7	37795	32285	26837	21052	16313	12873	10062	7615	5673	4030	2543
0.8	37231	31721	26273	20488	15749	12309	9498	7051	5109	3466	1979
0.9	36667	31157	25709	19924	15185	11745	8934	6487	4545	2902	1415
1.0	36103	30593	25145	19360	14621	11181	8370	5923	3981	2338	851
1.1	35539	30029	24581	18796	14057	10617	7806	5359	3417	1774	287
1.2	34975	29465	24017	18232	13493	10053	7242	4795	2853	1210	
1.3	34410	28901	23453	17668	12929	9489	6678	4231	2289	646	
1.4	33847	28337	22889	17104	12365	8925	6114	3667	1725	82	
1.5	33283	27773	22325	16540	11801	8361	5550	3103	1161		
1.6	32719	27209	21761	15976	11237	7797	4986	2539	597		
1.7	32155	26645	21197	15412	10673	7233	4422	1975	33		
1.8	31591	26081	20633	14848	10109	6669	3858	1411			
1.9	31027	25517	20069	14284	9545	6105	3294	847			
2.0	30463	24953	19505	13720	8981	5541	2730	283			

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET-104.

ENGINE No. 1293 to 1305.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
	10	15	20	25	30	35	40	45	50	55	60
[illegible]	41863	36295	30847	25063	20327	16886	14076	11631	9692	8049	6564
[illegible]	41409	35841	30393	24609	19873	16432	13622	11177	9238	7595	6110
[illegible]	40955	35387	29939	24155	19419	15978	13168	10723	8784	7141	5656
[illegible]	40501	34933	29485	23701	18965	15524	12714	10269	8330	6687	5202
[illegible]	[illegible]	34479	29031	23247	18511	15070	12260	9815	7876	6233	4748
[illegible]	[illegible]	34025	28579	22793	18057	14616	11806	9361	7422	5779	4294
[illegible]	[illegible]	33571	28123	22339	17603	14162	11352	8907	6968	5325	3840
[illegible]	[illegible]	33117	27669	21885	17149	13708	10898	8453	6514	4871	3386
[illegible]	[illegible]	32663	27215	21431	16695	13254	10444	7999	6060	4417	2932
[illegible]	[illegible]	32209	26761	20977	16241	12800	9990	7545	5606	3963	2478
[illegible]	[illegible]	31755	26307	20523	15787	12346	9536	7091	5152	3509	2024
[illegible]	[illegible]	31301	25853	20069	15333	11892	9082	6637	4698	3055	1570
[illegible]	[illegible]	30847	25399	19615	14879	11438	8628	6183	4244	2601	1116
[illegible]	[illegible]	30393	24945	19161	14425	10984	8174	5729	3790	2147	662
[illegible]	[illegible]	[illegible]	24491	18707	13971	10530	7720	5275	3336	1693	208
[illegible]	[illegible]	[illegible]	24037	18253	13517	10076	7266	4821	2882	1239	
[illegible]	[illegible]	[illegible]	23583	17799	13063	9622	6812	4367	2428	785	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12609	9168	6358	3913	1974	331	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12155	8714	5904	3459	1520		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11701	[illegible]	5450	3005	1066		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11247	7806	4996	2551	612		

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

ENGINE No. 1400 to 1409.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW-BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	31830	29712	26283	22915	19605	16277	13821	11699	9909	8348	6928
0.1	31420	29302	25873	22565	19195	15867	13411	11289	9499	7938	6518
0.2	31010	28892	25463	22155	18785	15457	13001	10879	9089	7528	6108
0.3	30600	28482	25053	21745	18375	15047	12591	10469	8679	7118	5698
0.4	30190	28072	24643	21335	17965	14637	12181	10059	8269	6708	5288
0.5	29780	27662	24233	20925	17555	14227	11771	9649	7859	6298	4878
0.6	29370	27252	23823	20515	17145	13817	11361	9239	7449	5888	4468
0.7	28960	26842	23413	20105	16735	13407	10951	8829	7039	5478	4058
0.8	28550	26432	23003	19695	16325	12997	10541	8419	6629	5068	3648
0.9	28140	26022	22593	19285	15915	12587	10131	8009	6219	4658	3238
1.0	27730	25612	22183	18875	15505	12177	9721	7599	5809	4248	2828
1.1	27320	25202	21773	18465	15095	11767	9311	7189	5399	3838	2418
1.2	26910	24792	21363	18055	14685	11357	8901	6779	4989	3428	2008
1.3	26500	24382	20953	17645	14275	10947	8491	6369	4579	3018	1598
1.4	26090	23972	20543	17235	13865	10537	8081	5959	4169	2608	1188
1.5	25680	23562	20133	16825	13455	10127	7671	5549	3759	2198	778
1.6	25270	23152	19723	16415	13045	9717	7261	5139	3349	1788	368
1.7	24860	22742	19313	16005	12635	9307	6851	4729	2939	1378	
1.8	24450	22332	18903	15595	12225	8897	6441	4319	2529	968	
1.9	24040	21922	18493	15185	11815	8487	6031	3909	2119	558	
2.0	23630	21512	18083	14775	11405	8077	5621	3499	1709	148	

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET-106

ENGINE No. 2001 to 2007.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL.										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	81040	64477	52744	41564	32504	24859	18630				
0.1	80362	63799	52066	40886	31826	24181	17952				
0.2	79684	63121	51388	40208	31148	23503	17274				
0.3	79006	62443	50710	39530	30470	22825	16596				
0.4	78328	61765	50032	38852	29792	22147	15918				
0.5	77650	61087	49354	38174	29114	21469	15240				
0.6	76972	60409	48676	37496	28436	20791	14562				
0.7	76294	59731	47998	36818	27758	20113	13884				
0.8	75616	59053	47320	36140	27080	19435	13206				
0.9	74938	58375	46642	35462	26402	18757	12528				
1.0	74260	57697	45964	34784	25724	18079	11850				
1.1	73582	57019	45286	34106	25046	17401	11172				
1.2	72904	56341	44608	33428	24368	16723	10494				
1.3	72226	55663	43930	32750	23690	16045	9816				
1.4	71548	54985	43252	32072	23012	15367	9138				
1.5	70870	54307	42574	31394	22334	14689	8460				
1.6	70192	53629	41896	30716	21656	14011	7782				
1.7	69514	52951	41218	30038	20978	13333	7104				
1.8	68836	52273	40540	29360	20300	12655	6426				
1.9	68158	51595	39862	28682	19622	11977	5748				
2.0	67480	50927	39184	28004	18944	11299	5070				

TABLE VII.—Showing Draw Bar Pull of Frisco Locomotives

SHEET- 107.

ENGINE No. 2232 TO 2235

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL.										
0.0	10953	10272	9092	7901	6672	5437	4420	3593	2832	2135	1522
0.1	10765	10084	8904	7713	6484	5249	4232	3405	2644	1947	1334
0.2	10567	9896	8716	7525	6296	5061	4044	3217	2456	1759	1146
0.3	10379	9708	8528	7337	6108	4873	3856	3029	2268	1571	958
0.4	10191	9520	8340	7149	5920	4685	3668	2841	2080	1383	770
0.5	10003	9332	8152	6961	5732	4497	3480	2653	1892	1195	582
0.6	9815	9144	7964	6773	5544	4309	3292	2465	1704	1007	394
0.7	9627	8956	7776	6585	5356	4121	3104	2277	1516	819	206
0.8	9439	8768	7588	6397	5168	3933	2916	2089	1328	631	18
0.9	9251	8580	7400	6209	4980	3745	2728	1901	1140	443	
1.0	9063	8392	7212	6021	4792	3557	2540	1713	952	255	
1.1	8875	8204	7024	5833	4604	3369	2352	1525	764	67	
1.2	8687	8016	6836	5645	4416	3181	2164	1337	576		
1.3	8499	7828	6648	5457	4228	2993	1976	1149	388		
1.4	8311	7640	6460	5269	4040	2805	1788	961	200		
1.5	8123	7452	6272	5081	3852	2617	1600	773	12		
1.6	7935	7264	6084	4893	3664	2429	1412	585			
1.7	7747	7076	5896	4705	3476	2241	1224	397			
1.8	[illegible]	6888	5708	4517	3288	2053	1036	209			
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3100	1865	848	21			
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2912	1677	660				

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET- 108.

ENGINE No. 2236-2237.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL. 10	15	20	25	30	35	40	45	50	55	60
0.0	11315	10522	9257	8001	6742	5447	4440	3588	2834	2125	1512
0.1	11127	10334	9069	7813	6564	5259	4252	3400	2646	1937	1324
0.2	10939	10146	8881	7625	6366	5071	4064	3212	2458	1749	1136
0.3	10751	9958	8693	7437	6178	4883	3876	3024	2270	1561	948
0.4	10563	9770	8505	7249	5990	4695	3688	2836	2082	1373	760
0.5	10375	9582	8317	7061	5802	4507	3500	2648	1894	1185	572
0.6	10187	9394	8129	6873	5614	4319	3312	2460	1706	997	384
0.7	9999	9206	7941	6685	5426	4131	3124	2272	1518	809	196
0.8	9811	9018	7753	6497	5238	3943	2936	2084	1330	621	
0.9	9623	8830	7565	6309	5050	3755	2748	1896	1142	433	
1.0	9435	8642	7377	6121	4862	3567	2560	1708	954	245	
1.1	9247	8454	7189	5933	4674	3379	2372	1520	766	57	
1.2	9059	8266	7001	5745	4486	3191	2184	1332	578		
1.3	8871	8078	6813	5557	4298	3003	1996	1144	390		
1.4	8683	7890	6625	5369	4110	2815	1808	956	202		
1.5	8495	7702	6437	5181	3922	2627	1620	768	14		
1.6	8307	7514	6249	4993	3734	2439	1432	580			
1.7	8119	7326	6061	4805	3546	2251	1244	392			
1.8	7931	7138	5873	4617	3358	2063	1056	204			
1.9	7743	6950	5685	4429	3170	1875	868	16			
2.0	7555	6762	5497	4241	2982	1687	680				

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET- 109.

ENGINE No. 2241

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
	10	15	20	25	30	35	40	45	50	55	60
[illegible]	10639	9604	8343	7039	5761	4592	3703	2917	2232	1575	1004
[illegible]	10459	9424	8163	6859	5581	4412	3523	2737	2052	1395	824
[illegible]	10279	9244	7983	6679	5401	4232	3343	2557	1872	1215	644
[illegible]	10099	9064	7803	6499	5221	4052	3163	2377	1692	1035	464
[illegible]	9919	8884	7623	6319	5041	3872	2983	2197	1512	855	284
[illegible]	9739	8704	7443	6139	4861	3692	2803	2017	1332	675	104
[illegible]	9559	8524	7263	5959	4681	3512	2623	1837	1152	495	
[illegible]	9379	8344	7083	5779	4501	3332	2443	1657	972	315	
[illegible]	9199	8164	6903	5599	4321	3152	2263	1477	792	135	
[illegible]	9019	7984	6723	5419	4141	2972	2083	1297	612		
[illegible]	8839	7804	6543	5239	3961	2792	1903	1117	432		
[illegible]	8659	7624	6363	5059	3781	2612	1723	937	252		
[illegible]	8479	7444	6183	4879	3601	2432	1543	757	72		
[illegible]	8299	7264	6003	4699	3421	2252	1363	577			
[illegible]	8119	7084	5823	4519	3241	2072	1183	397			
[illegible]	7939	6904	5643	4339	3061	1892	1003	217			
[illegible]	7759	6724	5463	4159	2881	1712	823	37			
[illegible]	7579	6544	5283	3979	2701	1532	643				
[illegible]	7399	6364	5103	3799	2521	1352	463				
[illegible]	7219	6184	4923	3619	2341	1172	283				
[illegible]	7039	6004	4743	3439	2161	992	103				

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET- 110.

ENGINE No. 2252.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	11251	10425	9143	7903	6582	5297	4323	3531	2751	2083	1450
0.1	11085	10259	8977	7737	6416	5131	4157	3365	2585	1917	1284
0.2	10919	10093	8811	7571	6250	4965	3991	3199	2419	1751	1118
0.3	10753	9927	8645	7405	6084	4799	3825	3033	2253	1585	952
0.4	10587	9761	8479	7239	5918	4633	3659	2867	2087	1419	786
0.5	10421	9595	8313	7073	5752	4467	3493	2701	1921	1253	620
0.6	10255	9429	8147	6907	5586	4301	3327	2535	1755	1087	454
0.7	10089	9263	7981	6741	5420	4135	3161	2369	1589	921	288
0.8	9923	9097	7815	6575	5254	3969	2995	2203	1423	755	122
0.9	9757	8931	7649	6409	5088	3803	2829	2037	1257	589	
1.0	9591	8765	7483	6243	4922	3637	2663	1871	1091	423	
1.1	9425	8599	7317	6077	4756	3471	2497	1705	925	257	
1.2	9259	8433	7151	5911	4590	3305	2331	1539	759	91	
1.3	9093	8267	6985	5745	4424	3139	2165	1373	593		
1.4	8927	8101	6819	5579	4258	2973	1999	1207	427		
1.5	8761	7935	6653	5413	4092	2807	1833	1041	261		
1.6	8595	7769	6487	5247	3926	2641	1667	875	95		
1.7	8429	7603	6321	5081	3760	2475	1501	709			
1.8	8263	7437	6155	4915	3594	2309	1335	543			
1.9	8097	7271	5989	4749	3428	2143	1169	377			
2.0	7931	7105	5823	4583	3262	1977	1003	211			

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

Sheet - III

ENGINE No. 2253 - 2255

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
	10	15	20	25	30	35	40	45	50	55	60
0.0	10316	9545	8363	7178	5982	4787	3873	3131	2394	1760	1159
0.1	10150	9379	8197	7012	5816	4621	3707	2965	2228	1594	993
0.2	9984	9213	8031	6846	5650	4455	3541	2799	2062	1428	827
0.3	9818	9047	7865	6680	5484	4289	3375	2632	1896	1262	661
0.4	9652	8881	7699	6514	5318	4123	3209	2467	1730	1096	495
0.5	9486	8715	7533	6348	5152	3957	3043	2301	1564	930	329
0.6	9320	8549	7367	6182	4986	3791	2877	2135	1398	764	163
0.7	9154	8383	7201	6016	4820	3625	2711	1969	1232	598	
0.8	8988	8217	7035	5850	4654	3459	2545	1803	1066	432	
0.9	8822	8051	6869	5684	4488	3293	2379	1637	900	266	
1.0	8656	7885	6703	5518	4322	3127	2213	1471	734	100	
1.1	8490	7719	6537	5352	4156	2961	2047	1305	568		
1.2	8324	7553	6371	5186	3990	2795	1881	1139	402		
1.3	8158	7387	6205	5020	3824	2629	1715	973	236		
1.4	7992	7221	6039	4854	3658	2463	1549	807	70		
1.5	7826	7055	5873	4688	3492	2297	1383	641			
1.6	7660	6889	5707	4522	3326	2131	1217	475			
1.7	7494	6723	5541	4356	3160	1965	1051	309			
1.8	7328	6557	5375	4190	2994	1799	885	143			
1.9	7162	6391	5209	4024	2828	1632	719				
2.0	6996	6225	5043	3858	2662	1467	553				

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

ENGINE No. 2260

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	[illegible]	10865	9528	8263	6887	5557	4553	3736	2931	2246	1596
0.1	[illegible]	10699	9362	8097	6721	5391	4387	3570	2765	2080	1430
0.2	[illegible]	[illegible]	9196	7931	6555	5225	4221	3404	2599	1914	1264
0.3	[illegible]	[illegible]	9030	7765	6389	5059	4055	3238	2435	1748	1098
0.4	[illegible]	10201	8864	7699	6223	4893	3889	3072	2267	1582	932
0.5	[illegible]	10035	8698	7433	6057	4727	3723	2906	2101	1416	766
0.6	[illegible]	9869	8532	7267	5891	4561	3557	2740	1937	1250	600
0.7	10557	9103	8366	7101	5725	4395	3391	2574	1769	1084	434
0.8	10391	9537	8200	6935	5559	4229	3225	2408	1603	918	268
0.9	10225	9371	8034	6769	5393	4063	3059	2242	1439	752	
1.0	10059	9205	1868	6603	5227	3897	2893	2076	1271	586	
1.1	9893	9039	7702	6437	5061	3731	2727	1910	1105	420	
1.2	9727	8873	7536	6271	4895	3565	2561	1744	1041	254	
1.3	9561	8707	7370	6105	4729	3399	2395	1578	773	88	
1.4	9395	8541	7204	5939	4563	3233	2229	1412	607		
1.5	9229	8375	7038	5773	4397	3067	2063	1246	443		
1.6	9063	8209	6872	5607	4231	2901	1897	1080	275		
1.7	8897	8043	6706	5441	4065	2735	1731	914			
1.8	[illegible]	7877	6540	[illegible]	3899	2569	1565	748			
1.9	8565	7711	6374	[illegible]	3733	2403	1399	582			
2.0	8399	7545	6208	[illegible]	3567	2237	1233	416			

TABLE VII– Showing Draw Bar Pull of Frisco Locomotives

SHEET - 113.

ENGINE No. 2263.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	12576	11365	9898	8393	6907	5567	4568	3676	2909	2193	1553
0.1	12410	11199	9732	8227	6741	5401	4402	3510	2743	2027	1387
0.2	12244	11033	9566	8061	6575	5235	4236	3344	2577	1861	1221
0.3	12078	10867	9400	7895	6409	5069	4070	3178	2411	1695	1055
0.4	11912	10701	9234	7729	6243	4903	3904	3012	2243	1529	889
0.5	11746	10535	9068	7563	6077	4737	3938	2846	2079	1363	723
0.6	11580	10369	8902	7397	5911	4571	3572	2680	1913	1197	557
0.7	11414	10203	8736	7231	5745	4405	3406	2514	1747	1031	391
0.8	11248	10037	8570	7065	5579	4239	3240	2348	1581	865	225
0.9	11082	9871	8404	6899	5413	4073	3074	2182	1415	699	59
1.0	10916	9705	8238	6733	5247	3907	2908	2016	1249	533	
1.1	10750	9539	8072	6567	5081	3741	2742	1850	1083	367	
1.2	10584	9373	7906	6401	4915	3575	2576	1684	917	201	
1.3	10418	9207	7740	6235	4749	3409	2410	1518	751	35	
1.4	10252	9041	7574	6069	4583	3243	2244	1352	585		
1.5	10086	8875	7408	5903	4417	3077	2078	1186	419		
1.6	9920	8709	7242	5737	4251	2911	1912	1020	253		
1.7	9754	8543	7076	5571	4085	2745	1746	854	87		
1.8	9588	8377	6910	5405	3919	2579	1580	688			
1.9	9422	8211	6744	5239	3753	2413	1414	522			
2.0	9256	8045	6578	5073	3587	2247	1248	356			

ENGINE No. 2264.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	11977	11158	9820	8498	7178	5824	4763	3904	3098	2403	1739
0.1	11803	10984	9646	8324	7004	5650	4589	3730	2924	2229	1565
0.2	11629	10810	9472	8150	6830	5476	4415	3556	2750	2055	1391
0.3	11455	10636	9298	7976	6656	5302	4241	3382	2576	1881	1217
0.4	11281	10462	9124	7802	6482	5128	4067	3208	2402	1707	1043
0.5	11107	10288	8950	7628	6308	4954	3893	3034	2228	1533	869
0.6	10933	10114	8776	7454	6134	4780	3719	2860	2054	1359	695
0.7	10759	9940	8602	7280	5960	4606	3545	2686	1880	1185	521
0.8	10585	9766	8428	7106	5786	4432	3371	2512	1706	1011	347
0.9	10411	9592	8254	6932	5612	4258	3197	2338	1532	837	173
1.0	10237	9418	8080	6758	5438	4084	3023	2164	1358	663	
1.1	10063	9244	7906	6584	5264	3910	2849	1990	1184	489	
1.2	9889	9070	7732	6410	5090	3736	2675	1816	1010	315	
1.3	9715	8896	7558	6236	4916	3562	2501	1642	836	141	
1.4	9541	8722	7384	6062	4742	3388	2327	1468	662		
1.5	9367	8548	7210	5888	4568	3214	2153	1294	488		
1.6	9193	8374	7036	5714	4394	3040	1979.	1120	314		
1.7	9019	8200	6862	5540	4220	2866	1805	946	140		
1.8	8845	8026	6688	5366	4046	2692	1631	772			
1.9	8671	7852	6514	5192	3872	2518	1457	598			
2.0	8497	7678	6340	5018	3698	2344	1283	424			

ENGINE No. 2266.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL. 10	15	20	25	30	35	40	45	50	55	60
0.0	13202	12253	10767	9304	7830	6368	5249	4355	3471	2723	2020
0.1	13028	12079	10593	9130	7656	6194	5075	4181	3297	2549	1846
0.2	12854	11905	10419	8956	7482	6020	4901	4007	3123	2375	1672
0.3	12680	11731	10245	8782	7308	5846	4727	3833	2949	2201	1498
0.4	12506	11557	10071	8608	7134	5672	4553	3659	2775	2027	1324
0.5	12332	11383	9897	8434	6960	5498	4379	3485	2601	1853	1150
0.6	12158	11209	9723	8260	6786	5324	4205	3311	2427	1679	976
0.7	11984	11035	9549	8086	6612	5150	4031	3137	2253	1505	802
0.8	11810	10861	9375	7912	6438	4976	3857	2963	2079	1331	628
0.9	11636	10687	9201	7738	6264	4802	3683	2789	1905	1157	454
1.0	11462	10513	9027	7564	6090	4628	3509	2615	1731	983	280
1.1	11288	10339	8853	7390	5916	4454	3335	2441	1557	809	106
1.2	11114	10165	8679	7216	5742	4280	3161	2267	1383	635	
1.3	10940	9991	8505	7042	5568	4106	2987	2093	1209	461	
1.4	10766	9817	8331	6868	5394	3932	2813	1919	1035	287	
1.5	10592	9643	8157	6694	5220	3758	2639	1745	861	113	
1.6	10418	9469	7983	6520	5046	3584	2465	1571	687		
1.7	10244	9295	7809	6346	4872	3410	2291	1397	513		
1.8	10070	9121	7635	6172	4698	3236	2117	1223	339		
1.9	9896	8947	7461	5998	4524	3062	1943	1049	165		
2.0	9722	8773	7287	5824	4350	2888	1769	875			

TABLE VII—Showing Draw Bar Pull [illegible]

SHEET [illegible]

ENGINE No. 2267.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL. 10	15	20	25	30	35	40	45	50	55	60
0.0	12133	11115	9718	8313	6917	5542	4558	3681	2920	2207	1583
0.1	11967	10949	9552	8147	6751	5376	4392	3515	2754	2041	1417
0.2	11801	10783	9386	7981	6585	5210	4226	3349	2588	1875	1251
0.3	11635	10617	9220	7815	6419	5044	4060	3183	2422	1709	1085
0.4	11469	10451	9054	7649	6253	4878	3894	3017	2256	1543	919
0.5	11303	10285	8888	7483	6087	4712	3728	2851	2090	1377	753
0.6	11137	10119	8722	7317	5921	4546	3562	2685	1924	1211	587
0.7	10971	9953	8556	7151	5755	4380	3396	2519	1758	1045	421
0.8	10805	9787	8390	6985	5589	4214	3230	2353	1592	879	255
0.9	10639	9621	8224	6819	5423	4048	3064	2187	1426	713	89
1.0	10473	9455	8058	6653	5257	3882	2898	2021	1260	547	
1.1	10307	9289	7892	6487	5091	3716	2732	1855	1094	381	
1.2	10141	9123	7726	6321	4925	3550	2566	1689	928	215	
1.3	9975	8957	7560	6155	4755	3384	2400	1523	762	49	
1.4	9809	8791	7394	5989	4593	3218	2234	1357	596		
1.5	9643	8625	7228	5823	4427	3052	2068	1191	430		
1.6	9477	8459	7062	5657	4257	2886	1902	1025	264		
1.7	9311	8293	6896	5491	4095	2720	1736	859	98		
1.8	9145	8127	6730	5325	3929	2554	1570	693			
1.9	8979	7961	6564	5159	3759	2388	1404	527			
2.0	8813	7795	6398	4993	3597	2222	1238	361			

TABLE VII Showing Draw Bar Pull of [illegible]

SHEET [illegible]

ENGINE No. 2274.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	11640	10789	9447	8173	6807	5569	4502	3640	2831	2132	1487
0.1	11440	10589	9247	1973	6607	5369	4302	3440	2631	1932	1287
0.2	11240	10389	9047	7773	6407	5169	4102	3240	2431	1732	1087
0.3	11040	10189	8847	7573	6207	4969	3902	3040	2231	1532	887
0.4	10840	9989	8647	7373	6007	4769	3702	2840	2031	1332	687
0.5	10640	9789	8447	7173	5807	4569	3502	2640	1831	1132	487
0.6	10440	9589	8247	6973	5607	4369	3302	2440	1631	932	287
0.7	10240	9389	8047	6773	5407	4169	3102	2240	1431	732	87
0.8	10040	9189	7847	6573	5207	3969	2902	2040	1231	532	
0.9	9840	8989	7647	6373	5007	3769	2702	1840	1031	332	
1.0	9640	8789	7447	6173	4807	3569	2502	1640	831	132	
1.1	9440	8589	7247	5973	4607	3369	2302	1440	631		
1.2	9240	8389	7047	5773	4407	3169	2102	1240	431		
1.3	9040	8189	6847	5573	4207	2969	1902	1040	231		
1.4	8840	7989	6647	5373	4007	2769	1702	840	31		
1.5	8640	7789	6447	5173	3807	2569	1502	640			
1.6	8440	7589	6247	4973	3607	2369	1302	440			
1.7	8240	7389	6047	4773	3407	2169	1102	240			
1.8	8000	7189	5847	4573	3207	1969	902	40			
1.9	7840	6989	5647	4373	3007	1769	702				
2.0	7640	6789	5447	4173	2807	1569	502				

ENGINE No. 2275.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	10285	9517	8332	7159	5962	4767	3854	3107	2377	1725	1140
0.1	10107	9339	8154	6981	5784	4589	3676	2929	2199	1547	962
0.2	9929	9161	7976	6803	5606	4411	3498	2751	2021	1369	784
0.3	9751	8983	7798	6625	5428	4233	3320	2573	1843	1191	606
0.4	9573	8805	7620	6447	5250	4055	3142	2395	1665	1013	428
0.5	9395	8627	7442	6269	5072	3877	2964	2217	1487	835	250
0.6	9217	8449	7264	6091	4894	3699	2786	2039	1309	657	72
0.7	9039	8271	7086	5913	4716	3521	2608	1861	1131	479	
0.8	8861	8093	6908	5735	4538	3343	2430	1683	953	301	
0.9	8683	7915	6730	5557	4360	3165	2252	1505	775	123	
1.0	8505	7737	6552	5379	4182	2987	2074	1327	597		
1.1	8327	7559	6374	5201	4004	2809	1896	1149	419		
1.2	8149	7381	6196	5023	3826	2631	1718	971	241		
1.3	7971	7203	6018	4845	3648	2453	1540	793	63		
1.4	7793	7025	5840	4667	3470	2275	1362	615			
1.5	7615	6847	5662	4489	3292	2097	1184	437			
1.6	7437	6669	5484	4311	3114	1919	1006	259			
1.7	7259	6491	5306	4133	2936	1741	828	81			
1.8	7081	6313	5128	3955	2758	1563	650				
1.9	6903	6135	4950	3777	2580	1385	472				
2.0	6725	5957	4772	3599	2402	1207	294				

TABLE VII.—Showing Draw Bar Pull of Frisco Locomotives

SHEET- 119.

ENGINE No. 2650, 2651, 2652, 2667, 2668.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	16268	14200	12097	9998	7940	6486	5272	4255	3338	2549	1847
0.1	16038	13970	11867	9768	7710	6256	5042	4025	3108	2319	1617
0.2	15808	13740	11637	9538	7480	6026	4812	3795	2878	2089	1387
0.3	15578	13510	11407	9308	7250	5796	4582	3565	2648	1859	1157
0.4	15348	13280	11177	9078	7020	5566	4352	3335	2418	1629	927
0.5	15118	13050	10947	8848	6790	5336	4122	3105	2188	1399	697
0.6	14888	12820	10717	8618	6560	5106	3892	2875	1958	1169	467
0.7	14658	12590	10487	8388	6330	4876	3662	2645	1728	939	237
0.8	14428	12360	10257	8158	6100	4646	3432	2415	1498	709	7
0.9	14198	12130	10027	7928	5870	4416	3202	2185	1268	479	
1.0	13968	11900	9797	7698	5640	4186	2972	1955	1038	249	
1.1	13738	11670	9567	7468	5410	3956	2742	1725	808	19	
1.2	13508	11440	9337	7238	5180	3726	2512	1495	578		
1.3	13278	11210	9107	7008	4950	3496	2282	1265	348		
1.4	13048	10980	8877	6778	4720	3266	2052	1035	118		
1.5	12818	10750	8647	6548	4490	3036	1822	805			
1.6	12588	10520	8417	6318	4260	2806	1592	575			
1.7	12358	10290	8187	6088	4030	2576	1362	345			
1.8	12128	10060	7957	5858	3800	2346	1132	115			
1.9	11898	9830	7727	5628	3570	2116	902				
2.0	11668	9600	7497	5398	3340	1886	672				

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET- 120.

ENGINE No. 2653.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	14788	14720	12801	10762	8792	7252	5963	4867	3911	3068	2342
0.1	14588	14520	12601	10562	8592	7052	5763	4667	3711	2868	2142
0.2	14388	14320	12401	10362	8392	6852	5563	4467	3511	2668	1942
0.3	14188	14120	12201	10162	8192	6652	5363	4267	3311	2468	1742
0.4	13988	13920	12001	9962	7992	6452	5163	4067	3111	2268	1542
0.5	13788	13720	11801	9762	7792	6252	4963	3867	2911	2068	1342
0.6	13588	13520	11601	9562	7592	6052	4763	3667	2711	1868	1142
0.7	13388	13320	11401	9362	7392	5852	4563	3467	2511	1668	942
0.8	13188	13120	11201	9162	7192	5652	4363	3267	2311	1468	742
0.9	12988	12920	11001	8962	6992	5452	4163	3067	2111	1268	542
1.0	12788	12720	10801	8762	6792	5252	3963	2867	1911	1068	342
1.1	12588	12520	10601	8562	6592	5052	3763	2667	1711	868	142
1.2	12388	12320	10401	8362	6392	4852	3563	2467	1511	668	
1.3	12188	12120	10201	8162	6192	4652	3363	2267	1311	468	
1.4	11988	11920	10001	7962	5992	4452	3163	2067	1111	268	
1.5	11788	11720	9801	7762	5792	4252	2963	1867	911	68	
1.6	11588	11520	9601	7562	5592	4052	2763	1667	711		
1.7	11388	11320	9401	7362	5392	3852	2563	1467	511		
1.8	11188	11120	9201	7162	5192	3652	2363	1267	311		
1.9	10988	10920	9001	6962	4992	3452	2163	1067	111		
2.0	10788	10720	8801	6762	4792	3252	1963	867			

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

Sheet 121.

ENGINE No. 2654.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
	10	15	20	25	30	35	40	45	50	55	60
0.0	14697	13086	11293	9464	7671	6282	5103	4101	3224	2443	1778
0.1	14469	12858	11065	9236	7443	6054	4875	3873	2996	2215	1550
0.2	14241	12630	10837	9008	7215	5826	4647	3645	2768	1987	1322
0.3	14013	12402	10609	8780	6987	5598	4419	3417	2540	1759	1094
0.4	13785	12174	10381	8552	6759	5370	4191	3189	2312	1531	866
0.5	13557	11946	10153	8324	6531	5142	3963	2961	2084	1303	638
0.6	13329	11718	9925	8096	6303	4914	3735	2733	1856	1075	410
0.7	13101	11490	9697	7868	6075	4686	3507	2505	1628	847	182
0.8	12873	11262	9469	7640	5847	4458	3279	2277	1400	619	
0.9	12645	11034	9241	7412	5619	4230	3051	2049	1172	391	
1.0	12417	10806	9013	7184	5391	4002	2823	1821	944	163	
1.1	12189	10578	8785	6956	5163	3774	2595	1593	716		
1.2	11961	10350	8557	6728	4935	3546	2367	1365	488		
1.3	11733	10122	8329	6500	4707	3318	2139	1137	260		
1.4	11505	9894	8101	6272	4479	3090	1911	909	32		
1.5	11277	9666	7873	6044	4251	2862	1683	681			
1.6	11049	9438	7645	5816	4023	2634	1455	455			
1.7	10821	9210	7417	5588	3795	2406	1227	225			
1.8	10593	8982	7189	5560	3567	2178	999				
1.9	10365	8754	6961	5132	3339	1950	771				
2.0	10137	8526	6733	4904	3111	1722	543				

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET- 122.

ENGINE No. 2657-2658.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	13643	13210	11418	9590	7803	6412	5234	4233	3358	2579	1906
0.1	13429	12996	11204	9376	7589	6198	5020	4019	3144	2365	1692
0.2	13215	12782	10990	9162	7375	5984	4806	3805	2930	2151	1478
0.3	13001	12568	10776	8948	7161	5770	4592	3591	2716	1937	1264
0.4	12787	12354	10562	8734	6947	5556	4378	3377	2502	1723	1050
0.5	12573	12140	10348	8520	6733	5342	4164	3163	2288	1509	836
0.6	12359	11926	10134	8306	6519	5128	3950	2949	2074	1295	622
0.7	12145	11712	9920	8092	6305	4914	3736	2735	1860	1081	408
0.8	11931	11498	9706	7878	6091	4700	3522	2521	1646	867	194
0.9	11717	11284	9492	7664	5877	4486	3308	2307	1432	653	
1.0	11503	11070	9278	7450	5663	4272	3094	2093	1218	439	
1.1	11289	10856	9064	7236	5449	4058	2880	1879	1004	225	
1.2	11075	10642	8850	7022	5235	3844	2666	1665	790	11	
1.3	10861	10428	8636	6808	5021	3630	2452	1451	576		
1.4	10647	10214	8422	6594	4807	3416	2238	1237	362		
1.5	10433	10000	8208	6380	4593	3202	2024	1023	148		
1.6	10219	9786	7994	6166	4379	2988	1810	809			
1.7	10005	9572	7780	5952	4165	2774	1596	595			
1.8	9791	9358	7566	5738	3951	2560	1382	381			
1.9	9577	9144	7352	5524	3737	2346	1168	167			
2.0	9363	8930	7138	5310	3523	2132	954				

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET- 123

ENGINE No. 2659 to 2666.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	15704	13821	11897	9918	7991	6479	5325	4267	3364	2574	1871
0.1	15472	13589	11665	9686	7759	6247	5093	4035	3132	2342	1639
0.2	15240	13357	11433	9454	7527	6015	4861	3803	2900	2110	1407
0.3	15008	13125	11201	9222	7295	5783	4629	3571	2668	1878	1175
0.4	14776	12893	10969	8990	7063	5551	4397	3339	2436	1646	943
0.5	14544	12661	10737	8758	6831	5319	4165	3107	2204	1414	711
0.6	14312	12429	10505	8526	6599	5087	3933	2875	1972	1182	479
0.7	14080	12197	10273	8294	6367	4855	3701	2643	1740	950	247
0.8	13848	11965	10041	8062	6135	4623	3469	2411	1508	718	15
0.9	13616	11733	9809	7830	5903	4391	3237	2179	1276	486	
1.0	13384	11501	9577	7598	5671	4159	3005	1947	1044	254	
1.1	13152	11269	9345	7366	5439	3927	2773	1715	812	22	
1.2	12920	11037	9113	7134	5207	3695	2541	1483	580		
1.3	12688	10805	8881	6902	4975	3463	2309	1251	348		
1.4	12456	10573	8649	6670	4743	3231	2077	1019	116		
1.5	12224	10341	8417	6438	4511	2999	1845	787			
1.6	11992	10109	8185	6206	4279	2767	1613	555			
1.7	11760	9877	7953	5974	4047	2535	1381	323			
1.8	11528	9645	7721	5742	3815	2303	1149	91			
1.9	11296	9413	7489	5510	3583	2071	917				
2.0	11064	9181	7257	5278	3351	1839	685				

SHEET-124.

ENGINE No. 2669.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	14722	13111	11317	9488	7691	6304	5125	4122	3244	2462	1786
0.1	14496	12885	11091	9262	7465	6078	4899	3896	3018	2236	1560
0.2	14270	12659	10865	9036	7239	5852	4673	3670	2792	2010	1334
0.3	14044	12433	10639	8810	7013	5626	4447	3444	2566	1784	1108
0.4	13818	12207	10413	8584	6787	5400	4221	3218	2340	1558	882
0.5	13592	11981	10187	8358	6561	5174	3995	2992	2114	1332	656
0.6	13366	11755	9961	8132	6335	4948	3769	2766	1888	1106	430
0.7	13140	11529	9735	7906	6109	4722	3543	2540	1662	880	204
0.8	12914	11303	9509	7680	5883	4496	3317	2314	1436	654	
0.9	12688	11077	9283	7454	5657	4270	3091	2088	1210	428	
1.0	12462	10851	9057	7228	5431	4044	2865	1862	984	202	
1.1	12236	10625	8831	7002	5205	3818	2639	1636	758		
1.2	12010	10399	8605	6776	4979	3592	2413	1410	532		
1.3	11784	10173	8379	6550	4753	3366	2187	1184	306		
1.4	11588	9947	8153	6324	4527	3140	1961	958	80		
1.5	11332	9721	7927	6098	4301	2914	1735	732			
1.6	11106	9495	7701	5872	4075	2688	1509	506			
1.7	10880	9269	7475	5646	3849	2462	1283	280			
1.8	10654	9043	7249	5420	3623	2236	1057	54			
1.9	10428	8817	7023	5194	3397	2010	831				
2.0	10202	8591	6797	4968	3171	1784	605				

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET-125.

ENGINE No. [illegible] TO 2675.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	16298	14232	12132	10031	7975	6522	5311	4297	3381	2596	1896
0.1	16078	14012	11912	9811	7755	6302	5091	4077	3161	2376	1676
0.2	15858	13792	11692	9591	7535	6082	4871	3857	2941	2156	1456
0.3	15638	13572	11472	9371	7315	5862	4651	3637	2721	1936	1236
0.4	15418	13352	11252	9151	7095	5642	4431	3417	2501	1716	1016
0.5	15198	13132	11032	8931	6875	5422	4211	3197	2281	1496	796
0.6	14978	12912	10812	8711	6655	5202	3991	2977	2061	1276	576
0.7	14758	12692	10592	8491	6435	4982	3771	2757	1841	1056	356
0.8	14538	12472	10372	8271	6215	4762	3551	2537	1621	836	136
0.9	14318	12252	10152	8051	5995	4542	3331	2317	1401	616	
1.0	14098	12032	9932	7831	5775	4322	3111	2097	1181	396	
1.1	13878	11812	9712	7611	5555	4102	2891	1877	961	176	
1.2	13658	11592	9492	7391	5335	3882	2671	1657	741		
1.3	13438	11372	9272	7171	5115	3662	2451	1437	521		
1.4	13218	11152	9052	6951	4895	3442	2231	1217	301		
1.5	12998	10932	8832	6731	4675	3222	2011	997	81		
1.6	12778	10712	8612	6511	4455	3002	1791	777			
1.7	12558	10492	8392	6291	4235	2782	1571	557			
1.8	12338	10272	8172	6071	4015	2562	1351	337			
1.9	12118	10052	7952	5851	3795	2342	1131	117			
2.0	11898	9832	7732	5631	3575	2122	911				

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET- 126.

ENGINE No. 2676 TO 2691.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	16129	14179	12198	10152	8175	6606	5420	4336	3413	2607	1894
0.1	15889	13939	11958	9912	7935	6366	5180	4096	3173	2367	1654
0.2	15649	13699	11718	9672	7695	6126	4940	3856	2933	2127	1414
0.3	15409	13459	11478	9432	7455	5886	4700	3616	2693	1887	1174
0.4	15169	13219	11238	9192	7215	5646	4460	3376	2453	1647	934
0.5	14929	12979	10998	8952	6975	5406	4220	3136	2213	1407	694
0.6	14689	12739	10758	8712	6735	5166	3980	2896	1973	1167	454
0.7	14449	12499	10518	8472	6495	4926	3740	2656	1733	927	214
0.8	14209	12259	10278	8232	6255	4686	3500	2416	1493	687	
0.9	13969	12019	10038	7992	6015	4446	3260	2176	1253	447	
1.0	13729	11779	9798	7752	5775	4206	3020	1936	1013	207	
1.1	13489	11539	9558	7512	5535	3966	2780	1696	773		
1.2	13249	11299	9318	7272	5295	3726	2540	1456	533		
1.3	13009	11059	9078	7032	5055	3486	2300	1216	293		
1.4	12769	10819	8838	6792	4815	3246	2060	976	53		
1.5	12529	10579	8598	6552	4575	3006	1820	736			
1.6	12289	10339	8358	6312	4335	2766	1580	496			
1.7	12049	10099	8118	6072	4095	2526	1340	256			
1.8	11809	9859	7878	5832	3855	2286	1100	16			
1.9	11569	9619	7638	5592	3615	2046	860				
2.0	11329	9379	7398	5352	3375	1806	620				

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET-127.

ENGINE No. 2692 TO 2695.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	17429	15221	12969	10730	8540	6990	5701	4625	3664	2831	2095
0.1	17211	15003	12751	10512	8322	6772	5483	4407	3446	2613	1877
0.2	16993	14785	12533	10294	8104	6554	5265	4189	3228	2395	1659
0.3	16775	14567	12315	10076	7886	6336	5047	3971	3010	2177	1441
0.4	16557	14349	12097	9858	7668	6118	4829	3753	2792	1959	1223
0.5	16339	14131	11879	9640	7450	5900	4611	3535	2574	1741	1005
0.6	16120	13913	11661	9422	7232	5682	4393	3317	2356	1523	787
0.7	15903	13695	11443	9204	7014	5464	4175	3099	2138	1305	569
0.8	15685	13477	11225	8986	6796	5246	3957	2881	1920	1087	351
0.9	15467	13259	11007	8768	6578	5028	3739	2663	1702	869	133
1.0	15249	13041	10789	8550	6360	4810	3521	2445	1484	651	
1.1	15031	12823	10571	8332	6142	4592	3303	2227	1266	433	
1.2	14813	12605	10353	8114	5924	4374	3085	2009	1048	215	
1.3	14595	12387	10135	7896	5706	4156	2867	1791	830		
1.4	14377	12169	9917	7678	5488	3938	2649	1573	612		
1.5	14159	11951	9699	7460	5270	3720	2431	1355	394		
1.6	13941	11733	9481	7242	5052	3502	2213	1137	176		
1.7	13723	11515	9263	7024	4834	3284	1995	919			
1.8	13505	11297	9045	6806	4616	3066	1777	701			
1.9	13287	11079	8827	6588	4398	2848	1559	483			
2.0	13069	10861	8609	6370	4180	2630	1341	265			

TABLE VII—Showing Draw Bar Pull of Frisco Locomotives

SHEET- 128.

ENGINE No. 2698.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	17669	16436	14497	12611	10695	8802	7412	6302	5219	4326	3495
0.1	17393	16160	14221	12335	10419	8526	7136	6026	4943	4050	3219
0.2	17117	15884	13945	12059	10143	8250	6860	5750	4667	3774	2943
0.3	16841	15608	13669	11783	9867	7974	6584	5474	4391	3498	2667
0.4	16565	15332	13393	11507	9591	7698	6308	5198	4115	3222	2391
0.5	16289	15056	13117	11231	9315	7422	6032	4922	3839	2946	2115
0.6	16013	14780	12841	10955	9039	7146	5756	4646	3563	2670	1839
0.7	15737	14504	12565	10679	8763	6870	5480	4370	3287	2394	1563
0.8	15461	14228	12289	10403	8487	6594	5204	4094	3011	2118	1287
0.9	15185	13952	12013	10127	8211	6318	4928	3818	2735	1842	1011
1.0	14909	13676	11737	9851	7935	6042	4652	3542	2459	1566	735
1.1	14633	13400	11461	9575	7659	5766	4376	3266	2183	1290	459
1.2	14357	13124	11185	9299	7383	5490	4100	2990	1907	1014	183
1.3	14081	12848	10909	9023	7107	5214	3824	2114	1631	738	
1.4	13805	12572	10633	8747	6831	4938	3548	2438	1355	462	
1.5	13529	12296	10357	8471	6555	4662	3272	2162	1079	186	
1.6	13253	12020	10081	8195	6279	4386	2996	1886	803		
1.7	12977	11744	9805	7919	6003	4110	2720	1610	527		
1.8	12701	11468	9529	7643	5727	3834	2444	1334	251		
1.9	12425	11192	9253	7367	5451	3558	2168	1058			
2.0	12149	10916	8977	7091	5115	3282	1892	782			

TABLE VII Showing Draw Bar Pull of Frisco Locomotives

ENGINE No. 2700 to 2715

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL 10	15	20	25	30	35	40	45	50	55	60
0.0	21534	18719	15850	12986	10403	8458	7054	5742	4647	3717	2865
0.1	21292	18477	15608	12744	10161	8216	6812	5500	4405	3475	2623
0.2	21050	18235	15366	12502	9919	7974	6570	5258	4163	3233	2381
0.3	20808	17993	15124	12260	9677	7732	6328	5016	3921	2991	2139
0.4	20566	17751	14882	12018	9435	7490	6086	4774	3679	2749	1897
0.5	20324	17509	14640	11776	9193	7248	5844	4532	3437	2507	1655
0.6	20082	17267	14398	11534	8951	7006	5602	4290	3195	2265	1413
0.7	19840	17025	14156	11292	8709	6764	5360	4048	2953	2023	1171
0.8	19598	16783	13914	11050	8467	6522	5118	3806	2711	1781	929
0.9	19356	16541	13672	10808	8225	6280	4876	3564	2469	1539	687
1.0	19114	16299	13430	10566	7983	6038	4634	3322	2227	1297	445
1.1	18872	16057	13188	10324	7741	5796	4392	3080	1985	1055	203
1.2	18630	15815	12946	10082	7499	5554	4150	2838	1743	813	
1.3	18388	15573	12704	9840	7257	5312	3908	2596	1501	571	
1.4	18146	15331	12462	9598	7015	5070	3666	2354	1259	329	
1.5	17904	15089	12220	9356	6773	4828	3424	2112	1017	87	
1.6	17662	14847	11978	9114	6531	4586	3182	1870	775		
1.7	17420	14605	11736	8872	6289	4344	2940	1628	533		
1.8	17178	14363	11494	8630	6047	4102	2698	1386	291		
1.9	16936	14121	11252	8388	5805	3860	2456	1144	49		
2.0	16694	13879	11010	8146	5563	3618	2214	902			

TABLE VII Showing Draw Bar Pull of Frisco Locomotives

Sheet 136

ENGINE No. 2716 to 2719.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	21582	18768	15899	13036	10453	8311	7107	5797	4702	3774	2922
0.1	21364	18550	15681	12818	10235	8093	6889	5579	4484	3556	2704
0.2	21146	18332	15463	12600	10017	7875	6671	5361	4266	3338	2486
0.3	20928	18114	15245	12382	9799	7657	6453	5143	4048	3120	2268
0.4	20710	17896	15027	12164	9581	7439	6235	4925	3830	2902	2050
0.5	20492	17678	14809	11946	9363	7221	6017	4707	3612	2684	1832
0.6	20274	17460	14591	11728	9145	7003	5799	4489	3394	2466	1614
0.7	20056	17242	14373	11510	8927	6785	5581	4271	3176	2248	1396
0.8	19838	17024	14155	11292	8709	6567	5363	4053	2958	2030	1178
0.9	19620	16806	13937	11074	8491	6349	5145	3835	2740	1812	960
1.0	19402	16588	13719	10856	8273	6131	4927	3617	2522	1594	742
1.1	19184	16370	13501	10638	8055	5913	4709	3399	2304	1376	524
1.2	18966	16152	13283	10420	7837	5695	4491	3181	2086	1158	306
1.3	18748	15934	13065	10202	7619	5477	4273	2963	1768	940	88
1.4	18530	15716	12847	9984	7401	5259	4055	2745	1650	722	
1.5	18312	15498	12629	9766	7183	5041	3837	2527	1432	504	
1.6	18094	15280	12411	9548	6965	4823	3619	2309	1214	286	
1.7	17876	15062	12193	9330	6747	4605	3401	2091	996	68	
1.8	17658	14844	11975	9112	6529	4387	3183	1873	778		
1.9	17440	14626	11757	8894	6311	4169	2965	1655	560		
2.0	17222	14408	11539	8676	6093	3951	2747	1437	342		

TABLE VII Showing Draw Bar Pull of Frisco Locomotives

ENGINE No. 2720 to 2723.

GRADE PER CENT	10	15	20	25	30	35	40	45	50	55	60
	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
0.0	21513	18698	15829	12965	10382	8437	7033	5721	4626	3696	2844
0.1	21299	18484	15615	12751	10168	8223	6819	5507	4412	3482	2630
0.2	21085	18270	15401	12537	9954	8009	6605	5293	4198	3268	2416
0.3	20871	18056	15187	12323	9740	7795	6391	5079	3984	3054	2202
0.4	20657	17842	14973	12109	9526	7581	6177	4865	3770	2840	1988
0.5	20443	17628	14759	11895	9312	7367	5963	4651	3556	2626	1774
0.6	20229	17414	14545	11681	9098	7153	5749	4437	3342	2412	1560
0.7	20015	17200	14331	11467	8884	6939	5535	4223	3128	2198	1346
0.8	19801	16986	14117	11253	8670	6725	5321	4009	2914	1984	1132
0.9	19587	16772	13903	11039	8456	6511	5107	3795	2700	1770	918
1.0	19373	16558	13689	10825	8242	6297	4893	3581	2486	1556	704
1.1	19159	16342	13475	10611	8028	6083	4679	3367	2272	1342	490
1.2	18945	16130	13261	10397	7814	5869	4465	3153	2058	1128	276
1.3	18731	15916	13047	10183	7600	5655	4251	2939	1844	914	62
1.4	18517	15702	12833	9969	7386	5441	4037	2725	1630	700	
1.5	18303	15488	12619	9755	7172	5227	3823	2511	1416	486	
1.6	18089	15274	12405	9541	6958	5013	3609	2297	1202	272	
1.7	17875	15060	12191	9327	6744	4799	3395	2083	988	58	
1.8	17661	14846	11977	9113	6530	4585	3181	1869	774		
1.9	17447	14632	11763	8899	6316	4371	2967	1655	560		
2.0	17233	14418	11549	8685	6102	4157	2753	1441	346		

ENGINE No. 2724 TO 2730.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	23024	20040	16981	13928	11175	9218	7609	6224	5069	4091	3195
0.1	22776	19792	16733	13680	10927	8970	7361	5976	4821	3843	2947
0.2	22528	19544	16485	13432	10679	8722	7113	5728	4573	3595	2699
0.3	22280	19296	16237	13184	10431	8474	6865	5480	4325	3347	2451
0.4	22032	19048	15989	12936	10183	8226	6617	5232	4077	3099	2203
0.5	21784	18800	15741	12688	9935	7978	6369	4984	3829	2851	1955
0.6	21536	18552	15493	12440	9687	7730	6121	4736	3581	2603	1707
0.7	21288	18304	15245	12192	9439	7482	5873	4488	3333	2355	1459
0.8	21040	18056	14997	11944	9191	7234	5625	4240	3085	2107	1211
0.9	20792	17804	14749	11696	8943	6986	5377	3992	2837	1859	963
1.0	20544	17560	14501	11448	8695	6738	5129	3744	2589	1611	715
1.1	20296	17308	14253	11200	8447	6490	4881	3496	2341	1363	467
1.2	20048	17064	14005	10952	8199	6242	4633	3248	2093	1115	219
1.3	19800	16812	13757	10704	7951	5994	4385	3000	1845	867	
1.4	19552	16568	13509	10456	7703	5746	4137	2752	1597	619	
1.5	19304	16316	13261	10208	7455	5498	3889	2504	1349	371	
1.6	19056	16072	13013	9960	7207	5250	3641	2256	1101	123	
1.7	18808	15820	12765	9712	6959	5002	3393	2008	853		
1.8	18560	15576	12517	9464	6711	4754	3145	1760	605		
1.9	18312	15324	12269	9216	6463	4506	2897	1512	357		
2.0	18064	15080	12021	8968	6215	4258	2649	1264	109		

TABLE VII Showing Draw Bar Pull of [illegible] Locomotives

ENGINE No. 2731 to 2733.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL. 10	15	20	25	30	35	40	45	50	55	60
0.0	23161	20667	17528	14375	11532	9515	7871	6446	5256	4253	3337
0.1	23509	20415	17276	14123	11280	9263	7619	6194	5004	4001	3085
0.2	23257	20163	17024	13871	11028	9011	7367	5942	4752	3749	2833
0.3	23005	19911	16772	13619	10776	8759	7115	5690	4500	3497	2581
0.4	22753	19659	16520	13367	10524	8507	6863	5438	4248	3245	2329
0.5	22501	19407	16268	13115	10272	8255	6611	5186	3996	2993	2077
0.6	22249	19155	16016	12863	10020	8003	6359	4934	3744	2741	1825
0.7	21997	18903	15764	12611	9768	7751	6107	4682	3492	2489	1573
0.8	21745	18651	15512	12359	9516	7499	5855	4430	3240	2237	1321
0.9	21493	18399	15260	12107	9264	7247	5603	4178	2988	1985	1069
1.0	21241	18147	15008	11855	9012	6995	5351	3926	2736	1733	817
1.1	20989	17895	14756	11603	8760	6743	5099	3674	2484	1481	565
1.2	20737	17643	14504	11351	8508	6491	4847	3422	2232	1229	313
1.3	20485	17391	14252	11099	8256	6239	4595	3170	1980	977	
1.4	20233	17139	14000	10847	8004	5987	4343	2918	1728	725	
1.5	19981	16887	13748	10595	7752	5735	4091	2666	1476	473	
1.6	19729	16635	13496	10343	7500	5483	3839	2414	1224	221	
1.7	19477	16383	13244	10091	7248	5231	3587	2162	972		
1.8	19225	16131	12992	9839	6996	4979	3335	1910	720		
1.9	18973	15879	12740	9587	6744	4727	3083	1658	468		
2.0	18721	15627	12488	9335	6492	4475	2831	1406	216		

TABLE VII.—Showing Draw Bar Pull of Frisco Locomotives

SHEET-134.

ENGINE No. 2735.

GRADE	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
PER CENT	10	15	20	25	30	35	40	45	50	55	60
0.0	18443	16028	13550	11061	8825	7216	5899	4747	3783	2947	2198
0.1	18225	15810	13332	10843	8607	6998	5681	4529	3565	2729	1980
0.2	18007	15592	13114	10625	8389	6780	5463	4311	3347	2511	1762
0.3	17789	15374	12896	10407	8171	6562	5245	4093	3129	2293	1544
0.4	17571	15156	12678	10189	7953	6344	5027	3875	2911	2075	1326
0.5	17353	14938	12460	9971	7735	6126	4809	3657	2693	1857	1108
0.6	17135	14720	12242	9753	7517	5908	4591	3439	2475	1639	890
0.7	16917	14502	12024	9535	7299	5690	4373	3221	2257	1421	672
0.8	16699	14284	11806	9317	7081	5472	4155	3003	2039	1203	454
0.9	16481	14066	11588	9099	6863	5254	3937	2785	1821	985	236
1.0	16263	13848	11370	8881	6645	5036	3719	2567	1603	767	18
1.1	16045	13630	11152	8663	6427	4818	3501	2349	1385	549	
1.2	15827	13412	10934	8445	6209	4600	3283	2131	1167	331	
1.3	15609	13194	10716	8227	5991	4382	3065	1913	949	113	
1.4	15391	12976	10498	8009	5773	4164	2847	1695	731		
1.5	15173	12758	10280	7791	5555	3946	2629	1477	513		
1.6	14955	12540	10062	7573	5337	3728	2411	1259	295		
1.7	14737	12322	9844	7355	5119	3510	2193	1041	77		
1.8	14519	12104	9626	7137	4901	3292	1975	823			
1.9	14301	11886	9408	6919	4683	3074	1757	605			
2.0	14083	11668	9190	6701	4465	2856	1539	387			

TABLE VII Showing Draw Bar Pull of [illegible] Locomotives

ENGINE No. 2737.

GRADE PER CENT	SPEED IN MILES PER HOUR AND CORRESPONDING DRAW BAR PULL										
	10	15	20	25	30	35	40	45	50	55	60
0.0	20023	17418	14740	12071	9660	7936	6521	5292	4268	3382	2588
0.1	19805	17200	14522	11853	9442	7718	6303	5074	4050	3164	2370
0.2	19587	16982	14304	11635	9224	7500	6085	4856	3832	2946	2152
0.3	19369	16764	14086	11417	9006	7282	5867	4638	3614	2728	1934
0.4	19151	16546	13868	11199	8788	7064	5649	4420	3396	2510	1716
0.5	18933	16328	13650	10981	8570	6846	5431	4202	3178	2292	1498
0.6	18715	16110	13432	10763	8352	6628	5213	3984	2960	2074	1280
0.7	18497	15892	13214	10545	8134	6410	4995	3766	2742	1856	1062
0.8	18279	15674	12996	10327	7916	6192	4777	3548	2524	1638	844
0.9	18061	15456	12778	10109	7698	5974	4559	3330	2306	1420	626
1.0	17843	15238	12560	9891	7480	5756	4341	3112	2088	1202	408
1.1	17625	15020	12342	9673	7262	5538	4123	2894	1870	984	190
1.2	17407	14802	12124	9455	7044	5320	3905	2676	1652	766	
1.3	17189	14584	11906	9237	6826	5102	3687	2458	1434	548	
1.4	16971	14366	11688	9019	6608	4884	3469	2240	1216	330	
1.5	16753	14148	11470	8801	6390	4666	3251	2022	998	112	
1.6	16535	13930	11252	8583	6172	4448	3033	1804	780		
1.7	16317	13712	11034	8365	5954	4230	2815	1586	562		
1.8	16099	13494	10816	8147	5736	4012	2597	1368	344		
1.9	15881	13276	10598	7929	5518	3794	2379	1150	126		
2.0	15663	13058	10380	7711	5300	3576	2161	932			

As stated elsewhere in this report the minimum safe spped is estimated to be 10 miles per hour to prevent stalling. Inspection of table VII shows that the draw bar pull is a maximum at such speed, and the train resistance less than at any higher speed. Hence it is apparent that the maximum tonnage which can be hauled by a given engine will be at a speed of about ten miles per hour, or the lowest safe speed limit. It is probable that the tractive effort is actually greater at four or five miles per hour than at ten, but such low speed cannot be used practically without frequent stalling, hence we may say that for practical purposes the maximum tonnage will be that estimated for a speed of ten miles per hour.

For slow freight or drag service the comparative value of two engines in point of cars handled should then be made on the basis of ten miles per hour maintained speed on the ruling gradient, provided such speed will permit of the train getting over the road in the allowable time. For green ball or merchandise service, the maintained speed on the ruling grade may necessarily be greater than ten miles per hour in order to get the train over the division within the time limit. In such case the comparative value of any two engines for such service should be made on the basis of the minimum permissible speed on the ruling grade. In the latter case, however, there is another important point to be considered, which is dependent on the fact that the draw bar pull of the two engines being compared does not necessarily decrease in the same ratio as the speed increases. For this reason the average speed which may be maintained by the two engines under consideration must be determined. As the determination of this average speed involves the question of acceleration and velocity or momentum grades, it will not be considered at this place, but will be discussed under the head of velocity grades.

In so far as the question of tonnage or cars which may be hauled on the ruling grade is concerned, the determination may be made with the figures already given. For example, suppose it is desired to rate engines 727 tp 741, and engines 1200 to 1225 between Springfield and Monett west-bound, and for ordinary slow freight service. An inspection of the profile shows the ruling grade west-bound between the points mentioned is a 1.1 per cent grade, correcting for curvature by Table II. In the discussionof train resistance, given later, it is brought out that the average weight of cars on the Frisco is approximately 35 tons. From sheet 86 of Table VII, the draw bar pull of engines 724 tp 741 at ten miles per hour on a one and one-tenth per cent grade is found to be 26959 lbs. The total resistance per ton for 35-ton cars at ten miles per hour on a 1.1 per cent grade is found to be 27.2 lbs. By the formula given above, the number of tons which can be hauled will be 990. The published time card rating for engines 724 tp 741 between Springfield and Monett west-bound is 1000 tons, or ten tons in excess of the theoretical rating. The same calculations for engines 1200 to 1225 show a theoretical rating of 1270 tons, while the published time card rating is 1280 tons. These examples are given to show that the theoretical rating and actual rating determined from experiment agree very closely.

East-bound between Monett and Springfield the ruling grade is 1.5 per cent between Globe and Verona, commonly known as Globe Hill. The theoretical rating for engines 724 to 741 would be 720 tons, while the time card rating is 1000 tons. It is evident this rating cannot be hauled on Globe Hill without helper service from Monett yard, although the 1000 ton rating would apply east of Globe as the ruling grade east of Globe is only 1.1 per cent. The theoretical train handling between Monett and Springfield east-bound would be either to take 1000 tons out of Monett yard with switch engine service to a point three miles east, from which the 33-class engine could handle the train to Springfield, or else take 720 tons out of Monett without helper service, and fill the tonnage with pick-ups between Globe and Springfield. As a matter of fact both of these things are done, and no attempt is made to haul 1000-ton trains out of Monett without helper service to Globe or else doubling Globe Hill.

The ratings above given are for the estimated average load. It is apparent that the tonnage rating would be considerably different if all empties were handled or if all loads were handled. Assuming the average weight of cars in a train of empties at 25 tons, and in a train of all loads at 45 tons, a comparison of the west-bound rating for engines 727 to 741 and 1200 to 1225 for 25, 35 and 45 ton cars and ten miles per hour speed would be as follows:-

	724 to 741 Tonnage.	1200 to 1225 Tonnage.
25 - ton cars,	950	1206
35 - ton cars,	990	1270
45 - ton cars,	1025	1308

For engines 727 to 741 the rating for 25-ton cars would be about three per cent less than the rating for 35-ton cars, and for 45-ton cars about five per cent more. For engines 1200 to 1225, the rating for 25-ton cars would be about five per cent less than the rating for 35-ton cars, and for 45-ton cars about four per cent more. A provision should be made in the published rating for, say five per cent additional tonnage for all loads, and a reduction of five per cent in the published rating for all empties.

In order to compare the theoretical tonnage rating with actual engine performance there is given below a brief statement of certain tonnage tests and recommendations made by Mr. R. F. Carr while Inspector of Train and Station Service, together with a comparison between his recommendation and the results which might be expected from calculated performance of engines at the points mentioned.

On March 6, 1911, a test train was taken out of Harvard, Arkansas, noth-bound with 1818 tons consisting of 32 loads, with engine 672, 20" x 26" cylinder, 63" driving wheels, and 200 lbs. boiler pressure at blow off. This engine is tonnage class 28 in the published time card rating. Loads averaged practically 57 tons per car including the weight of car. With 200 lbs. steam pressure engine stalled at Mile 354 plus 22 poles on .75% grade with reverse lever in corner, and stalled at Mile 340 plus 32 poles on .80% grade with 200 lbs. steam and reverse lever in corner. The engine also stalled at other points, due to not maintaining steam pressure. Between Miles 347 and 348, engine stalled on 1.00% grade with 170 lbs. steam pressure. At this point there is practically one mile of one per cent grade. At mile 354, there is 3000 feet of tangent track on .75% grade, and at Mile 340 plus 32 poles there is 4000 feet of .80% grade, after correction for curvature. From sheet 77 of table VII, the draw bar pull of engine 672 on .75% grade is 23782# and on .80% grade 23617#. The total resistance to be overcome on the .75% grade would be 33798# with only 23782# available draw bar pull. The total resistance to be overcome on .80% grade would be 35616#, with only 23617# available draw bar pull. The total resistance per car on .75% grade would be 1056 lbs., or 22 cars of that weight could be handled, or 1250 tons instead of 1818. On the .80% grade the total resistance per car would be 1113 lbs. or 21 cars could be handled, or 1193 tons. It is apparent then that the engine could not have handled the 1818-ton train without assistance on the grades indicated, after the effects of velocity had been lost.

The recommendations in the above case were as follows:

1.-Between Miles 347 and 348 reduce the grade to a .6 per cent compensated.

2.-Between Miles 354 and 355 reduce the grade to a .6 per cent compensated.

3.-Between Miles 340.7 and 341.5 reduce the grade to a .6 per cent compensated.

The darw bar pull of engine #672 on a .6 per cent grade at ten miles per hour is taken from Table VII as 24277 lbs. The total resistance in the 1818-ton train at the same speed would be 28344 lbs. Or in other words if after the grade reduction the engine were still required to pull the train at a uniform speed of ten miles per hour, it could not do so, as the resistance would be about 4000 lbs greater than the draw bar pull. If the grades were reduced to .5% compensated, the available draw bar pull at ten miles per hour would be 24607 lbs. and the total resistance 24708 lbs., in which case the engine could probably handle the 1818-ton train under favorable conditions. These figures are on the basis that the velocity head would be lost before the summit of the grade was reached. As may be shown by figures given later, this would be the case between Miles 347 and 348 and between Miles 354 and 355, while between Miles 340.7 and 341.5 the reduction of grade as indicated would be sufficient to allow the engine to pull over the summit without reducing speed below ten miles per hour. At the first two points the reduction should be to a .5% compensated grade in order to handle the 1818-ton train.

THE ECONOMICAL RATE OF GRADE.

One of the most important features in connection with grade reduction work is the determination of the lowest grade line to be adopted. Or differently stated, to determine the point in the reduction in the rate of grade at which it will not be economical to further reduce the rate of grade. It has been stated by various writers that an engine will haul as much on a .3% grade as it can start on the level. If at 10 miles per hour the average train resistance is 6 lbs. per ton, the total train resistance on a .3% grade would be 12 lbs. per ton, while 16-lbs. per ton is ordinarily considered as the maximum starting resistance in single cars when bearings are cold. On such assumptions a .5% grade with cars offering 6 lbs. rolling resistance and 10-lbs grade resistance would equal the starting resistance.

The figure of 16-lbs per ton starting resistance for cars with bearings cold is probably very nearly correct as an average, and if a train were started with all bearings cold and all slack out of cars, it would of course be true that the starting resistance would probably average nearly 16-lbs per ton and there would be no advantage in reducing grades below a .5% grade. However, the common practice is to start a train with all the slack possible, especially if the engine has to start nearly or all of its full rating. In a long train it may be demonstrated that the first car can be given a sufficient initial velocity, before the second car starts to move, to propel that first car a greater distance than the full amount of slack in the train. That is, the car would travel such a distance if not attached to a following car. As the first car cannot travel further than the amount of slack between the first and second car without having its velocity checked, it actually gives up its kinetic energy in helping to overcome the starting resistance in the second and third cars, and so each car helps to overcome the starting resistance of the following cars. Now, while the initial friction in a car may be 16-lbs. per ton, as soon as that car is given a velocity of two or three miles per hour, the frictional, or simple tractive resistance may drop as low as three or four lbs. per ton. By making a very careful analysis of a number of cases of loading, and on different grades with different average weights per car; I find that 8-lbs per ton may be taken as representing quite accurately the average starting resistance, with this modification:-

As the rate of grade increases above about six or possibly seven tenths of one per cent, it is practically impossible to back cars up against each other in such a manner that the maximum slack may be obtained. The reason for this is that the cars will roll on a six or seven tenths per cent grade, hence we may modify the previous statement by saying that as the grade on which the train is started increases above about six-tenths of one per cent the virtual average starting resistance increases above 8 pounds per ton, probably approaching very nearly the full average starting resistance of each car on grades over one per cent. Good practice of course prevents very many cases where an engine has to start its rated full load on the maximum grade. For ordinary cases we may assume 8 pounds per ton as average starting resistance. On such an assumption, an engine should handle at ten miles per hour about the same tonnage on a .1 per cent grade that it could start on the level.

Any determination of the lowest economical rate of grade beased on starting resistanee will evidently contain a large personal equation factor, so far as the actual operation is concerned, depending on the individual engineer in handling his train. There is also another element to be considered, and that is the speed desirable, or the average speed to be maintained on the division. For example, on a division hauling a large coal tonnage or other slow moving freight, it would be desirable to have a flat grade in order that all the tonnage which could be started on the grade could be hauled on the ruling grade. As stated above, a .1 per cent grade is probably about the grade which would fulfill such conditions in actual practice. On the other hand, if we consider a division where the prevailing tonnage is merchandise or a class of freight requiring quick handling, the question of what train load may be handled over the division in a specified time is the important question and not how much may be started on a level grade. In such cases there are four factors to be considered--competition with other lines between the same points; facility of train's movement; determined practically from the total tonnage and number of trains; the average speed necessary to get the train over the division in the specified time, and the condition of the roadbed, limiting the maximum speed of trains. The latter factor should be determined as the maximum speed which may be made on the best track, as assumption should be made that eventually all track will be brought to the highest degree of perfection. On the Frisco Railroad the character of the country is such that where competing lines exist about the same condition of grades and distance occur, and where no reduction of grade has been made in either case the same tonnage is handled with very little difference in time. The mainquestion to be decided on this railroad, then, are the questions of facility of train movement and average speed. The former depends on the latter and on the amount of tonnage to be handled, and must be worked out for each division separately, depending on the leaving time of the merchandise or other fast trains. In another portion of this report it is stated that the extremes of speed for handling of freight trains should be 10 miles per hour for the slowest speed and 30 miles per hour for the fastest speed at which it is safe to run freight cars. If then, we determine the grade on which a train that may be handled at 30 miles per houron a level track ~~is~~ can be hauled at ten miles per hour maintained speed, there will evidently be no loss of energy by reason of having either more or less train load than can he handled under such conditions. Then if it is found that with such grades the time limit is not exceeded, it is reasonable to say that such a grade is the limiting economical grade.

To illustrate this point with a practical example, imagine a division with a 1.5 per cent ruling grade. It is at once evident that the train load which may be hauled at ten miles per hour on such a grade can be hauled much faster than 30 miles per hour on a level track. For example, engine 1226 will haul a 910-ton train of cars of 35-ton average weight at ten miles per hour on a 1.5 per cent grade, while on a level track the same engine will haul tha same train at a speed of about 47 miles per hour. In other words, the energy available could produce a speed of 47 miles per hour where only 30 miles per hour would be permissable, and the balance of power would be lost. If the same grade was reduced to a .2 per cent grade, we would find that the tonnage that could be handled at ten miles per hour on the .2 per cent grade could not be handled at thirty miles per hour on the level. Take for example, the same engine, #1226. On a .2 per cent grade this engine will theoretically handle 4150 tons, if the average weight of cars is 35 tons, or a train of 119 cars, at ten miles per hour. On a level grade the same engine will haul the same train at a maximum speed of about 22 miles per hour. In this case a thirty mile per hour track is being maintained and probably a thirty mile speed will be required on level track, where with an economical consumption of the energy, a speed of only 22 miles per hour should be maintained. If the grade were reduced to a .5% grade the same engine could handle exactly the same tonnage of cars of 35 tons average weight on the .5% grade at a speed of ten miles per hour that it could handle at 30 miles per hour on the level track. In which case there would be no loss of available energy and the .5 per cent grade might reasonably be said to be the economical grade, unless the saving which could be made in time would more than pay for the lost energy, together with the interest on the additional capital necessary to reduce the grade below a .5% compensated grade. However, it cannot be concluded that a .5% compensated grade is the economical grade for all engines or under all conditions. For comparison take the performance of engine #304 having about one-half the draw bar pull on a level track at ten miles per hour and compare its performance with that of engine #1226. At thirty miles per hour engine #304 can handle a train of 1290 tons of cars of 35 tons average weight, and the same train at ten miles per hour on a .39 per cent grade, so that we might say a .39 per cent grade was the economical grade for engine #304.

All the calculations given above are based on train of cars of 35-ton average weight, which as previously derived is about the average weight of cars making up Frisco trains. However, there will be trains of all empties averaging not over 20-tons per car and trains of all loads averaging about 70-tons per car. The economical grade for engine #1226 handling a train of 20-ton cars would be, on the same basis given above, a .6% grade, and the economical grade when handling 70-ton cars would be a .32 per cent grade. For engine #304 the economical grade with the train of 20-ton cars would be a .49 per cent grade and with the train of 70-ton cars a .25 per cent grade. Still another point is to be considered however. Where trains of empty cars are run, the average speed is reduced, and the same is true of trains of 70-ton cars which are usually coal trains or freight which does not have to be moved at speeds exceeding about twenty-five miles per hour, on level track. The economical grade for engine #1226 with all light cars then becomes a .44% grade and with all 70-ton cars a .21 per cent grade. For engine #304 the economical grade becomes a .34% grade for 20-ton cars and a .15% grade for 70-ton cars. A comparison of these figures indicates that the economical grade depends on the speed to be maintained on level track, on the particular engine used and on the average weight of cars handled. It also appears that as the weight of cars increase the economical rate of grade decreases, so that the ecomomical rate of grade today may not be the economical grade ten years hence, if the weight of cars still continues to increase as at present. If, However, the maintenance of our railroads ' with the increase in weight of cars, thus all(increase in speed, it appears from the analysis facts that the economical grade should remain about the same. By determining the economical grade for each engine or class of engines hauling different average weights of cars on the basis outlined above and then taking an average we should derive the most economical grade for the average conditions, and for the power in use on this railroad. It is evident that there will be a loss of energy in every case, unless the grade determined is actually the economical grade for certain engines, but this loss will be a minimum on the basis outlined. The following table shows the determination of this grade. In making up the table it is assumed the speed of trains of 20-tons and 70-tons car capacity will not exceed 25 miles per hour, and the speed of trains of 35-ton cars will not exceed 30 miles per hour. The reason for this is that trains of 20-ton and 70-ton cars are, in actual operation, nearly always trains of solid emptys or solid loads such as coal trains, either of which takes the drag freight schedule for reasons which are apparent, and the speeds will not have so great an allowable fluctuation, or possibly it would be better to say, a possible fluctuation, on account of the fact that the variation in tractive resistance will be less in each of these cases than in a mixed train. The same reason makes the acceleration slower and consequently affects the maximum speed. Merchandise trains on the other hand are usually given a faster schedule, which is the same as saying that the engine is given less than its rating in order to increase the average tractive power per ton of load, and consequently the acceleration.

The table further indicates that in general the economical rate of grade increases as the weight of engines increases, tending to offset somewhat the fact that the economical rate of grade decreases as the weight of cars increases. For example, engines in 800 and 900 class require about the same economical grade for 70-ton cars as a large number of the lightest engines in use require for 20-ton cars. The conclusion may be readily drawn that the economical rate of grade when once established will seldom, if ever, be less, the one case where this might occur being caused by a large increase in tonnage of heavy cars or the changing of the business of a portion of the road from merchandise to drag freight service.

Engs. No.	Av.Wt.Cars-20 T: Tonnage Rating OnLevel	Av.Wt.Cars-20 T: Economical Grade-%	Av.Wt.Cars-35 T: Tonnage Rating OnLevel	Av.Wt.Cars-35 T: Economical Grade %	Av.Wt.Cars-70 T: Tonnage Rating OnLevel	Av.Wt.Cars-70 T: Economical Grade %
26 = 27						
26 - 27	882	.25	948	.30	2001	.12
29	908	.22	952	.29	2061	.10
31	882	.24	946	.30	2000	.11
(32 and 33						
(38 and 40	883	.24	950	.29	2003	.11
34	882	.24	947	.29	2000	.11
35	880	.25	947	.32	1996	.12
43	994	.25	947	.32	2052	.12
44	912	.26	980	.32	2070	.12
45-46-47	914	.26	982	.32	2073	.12
48 - 52	922	.26	983	.33	2090	.12
53	954	.26	1019	.33	2163	.13
(54-56-60,						
(62-63,65,						
(67-68.	893	.29	946	.35	2026	.13
64	886	.27	942	.33	2012	.13
(69-70,72						
(73-74	877	.27	942	.32	1989	.12
75,78-90	886	.27	942	.33	2012	.13
91	870	.25	932	.30	1974	.12
92	894	.26	951	.33	2028	.13
93	976	.24	1024	.31	2212	.12
94	1005	.26	1081	.32	2281	.12
95	1014	.24	1067	.30	2300	.11
96-103	987	.27	1053	.33	2237	.13
104	999	.28	1063	.34	2267	.13
106-107	892	.25	950	.32	2025	.12
108-113	992	.25	1062	.31	2250	.12
114-115	1055	.26	1129	.33	2394	.13
130-135	1075	.23	1160	.28	2338	.12
136-137	1079	.19	1165	.24	2442	.10
138-143	1070	.26	1152	.32	2432	.13
144-145	1069	.27	1152	.32	2438	.13
146-147	1120	.32	1163	.39	2540	.15
148-151	1148	.26	1242	.31	2606	.12
152-154	1115	.21	1205	.26	2530	.10
155	934	.30	977	.37	2118	.14
156	1018	.20	1072	.27	2309	.09
157	984	.25	1061	.31	2232	.12
158	1184	.26	1281	.31	2686	.12
160	1198	.26	1279	.32	2718	.12
161	1033	.28	1098	.34	2345	.13
162	1050	.30	1102	.36	2383	.14
182-187	1330	.26	1436	.31	3016	.12
188-189	1331	.26	1440	.31	3020	.12
190-195	1487	.26	1605	.31	3372	.12
200-204	1680	.26	1820	.31	3810	.12
205-219	1665	.26	1805	.31	3780	.12
220-229	1668	.26	1807	.31	3785	.12
300-303	1281	.32	1333	.39	2906	.15

Engs. NO.	Av.Wt.Cars-20 T		Av. Wt.Cars-35T		Av.Wt.Cars-70 T	
	Tonnage Rating OnLevel	Economical Grade %	Tonnage Rating On Level	Economical Grade%	Tonnage Rating OnLevel	Economical Grade %
304-316	1240	.32	1292	.39	2811	.15
317-336	1234	.32	1284	.39	2800	.15
337-353	1326	.32	1380	.39	3010	.15
354-358	1321	.34	1362	.41	2996	.17
359-360	1378	.32	1424	.41	3124	.15
361-362	1547	.34	1605	.41	3510	.16
363-364	1555	.34	1615	.41	3520	.16
(400,402,						
(403,404	1157	.25	1202	.33	2623	.12
(401,405 &						
(406	1024	.32	1058	.40	2323	.15
407-409	1254	.21	1306	.28	2822	.10
(410,411-						
(413-415	1193	.32	1240	.39	2706	.15
416	1245	.29	1297	.36	2823	.13
417-421	1246	.27	1300	.34	2828	.12
426-427	1247	.27	1301	.34	2829	.12
428-437	1230	.30	1298	.36	2790	.14
448-458	1265	.32	1315	.39	2870	.15
438-447	1338	.26	1444	.32	3034	.12
459-466	1358	.32	1415	.39	3090	.15
487-490	1340	.30	1400	.37	3040	.14
491-500	1328	.37	1346	.45	3010	.17
501-504,						
506-515	1375	.36	1398	.44	3120	.16
516-520	1990	.30	2093	.37	4517	.14
521-530	2003	.30	2099	.37	4547	.14
539-548	1643	.26	1780	.31	3727	.12
549-557	1901	.30	2000	.37	4314	.14
558-567	1784	.30	1872	.37	4046	.14
568-572	1790	.30	1880	.37	4060	.14
573-574	1677	.30	1755	.37	4049	.14
575-584	1938	.38	1980	.44	4400	.17
585-594	1893	.30	1990	.37	4293	.14
(595-599						
(669-693	1895	.30	1992	.37	4297	.14
600-604	1784	.29	1880	.36	4040	.13
605-609	1774	.29	1873	.36	4022	.13
610-619	1992	.30	2097	.37	4520	.14
(620-623						
(634-668	1990	.30	2091	.37	4513	.14
624-628	2143	.23	2209	.31	4260	.11
629-633	2027	.26	2196	.31	4600	.12
(695-699						
(705-724	2120	.34	2180	.42	4809	.16
700-704	1764	.37	1845	.44	4000	.17
727-741	2125	.34	2188	.42	4820	.16
743-746,						
748,752-						
754,756-		see	next	page		

Engs. No.	Av.Wt.Cars-20 T: Tonnage Rating OnLevel	Av.Wt.Cars-20 T: Economical Grade %	Av.Wt.Cars-35 T: Tonnage Rating OnLevel	Av.Wt.Cars-35 T: Economical Grade %	Av.Wt.Cars-70 T: Tonnage Rating OnLevel	Av.Wt.Cars-70 T: Economical Grade %
(759,765-						
(770,772,						
(773,774	1878	.40	1944	.47	4260	.19
(742,747,						
(749-751,						
(755,760,						
(761,762,						
(775-799,						
(771,	2125	.34	2188	.42	4820	.16
801-818	1969	.40	2026	.47	4465	.19
819-828	2144	.40	2210	.47	4864	.19
829-833	2146	.40	2210	.47	4870	.19
834-835	1904	.47	1968	.54	4316	.22
950-955	2010	.42	2070	.50	4558	.20
956-965	2129	.40	2190	.47	4830	.19
970-989	2115	.42	2174	.49	4797	.20
1000-1009	1815	.26	1871	.31	4120	.12
1010-1014	1820	.26	1968	.31	4130	.12
1015-1039	2576	.29	2738	.35	5845	.13
1100-1111	2026	.26	2193	.31	4590	.12
1200-1225	2325	.44	2460	.49	5275	.21
1226-1265	2315	.44	2448	.49	5250	.21
1266-1280	2330	.38	2400	.46	5285	.18
1281-1292	2688	.37	2775	.45	6096	.17
1293-1305	2694	.38	2785	.45	6113	.18
1400-1409	2470	.26	2687	.31	5603	.12
2001-2007	4470	.50	4455	.60	10140	.23
2232-2235	850	.25	914	.31	1927	.11
2236-2237	861	.26	924	.32	1952	.12
2241	757	.30	789	.37	1717	.14
2252	850	.28	902	.34	1928	.13
2253,2255	772	.27	820	.33	1751	.12
2260	888	.27	944	.33	2015	.12
2263	902	.30	946	.37	2048	.14
2264	914	.27	983	.32	2073	.12
2266	1000	.27	1086	.32	2270	.12
2267	894	.29	947	.35	2028	.13
2274	879	.27	932	.33	1994	.12
2275	770	.27	817	.33	1746	.12
(2650-2652						
(2667,2668	1075	.36	1087	.44	2439	.17
2653	1157	.25	1206	.33	2625	.11
2654	1017	.32	1050	.40	2310	.15
2657,2658	1031	.27	1069	.34	2340	.12
2659-2666	1066	.34	1095	.41	2419	.16
2669	1020	.32	1054	.40	2315	.15
2670-2675	1078	.36	1092	.44	2447	.17
2676-2691	1092	.33	1120	.42	2476	.15
2692-2695	1154	.36	1170	.44	2618	.17
2698	1356	.26	1465	.32	3078	.12

Engs. No.	Av.Wt.Cars-20 T: Tonnage Rating On Level	Av.Wt.Cars-20 T: Economical Grade %	Av.Wt.Cars-35 T: Tonnage Rating On Level	Av.Wt.Cars-35 T: Economical Grade %	Av.Wt.Cars-70 T: Tonnage Rating On Level	Av.Wt.Cars-70 T: Economical Grade %
2700-2715	1396	.37	1426	.46	3167	.17
2716-2719	1402	.37	1433	.46	3180	.17
2720-2723	1395	.38	1423	.46	3163	.18
2724-2730	1497	.39	1531	.46	3398	.17
2731-2733	1545	.37	1580	.46	3507	.17
) 2735	1190	.37	1209	.46	2700	.17
2737	1298	.37	1323	.46	2945	.17
Average		.327		.395		.153

Note:-In order to shorten the tabulation given above all engines having the same specifications as to tractive effort, etc., are given together, as for instance engines 1400 to 1409, but in obtaining final average, each engine is included in the calculations.

Unless the tonnage of the three different weights of cars selected in the same, it will not be proper to take as the final result the average of the three rates of grade but rather a figure derived by assigning to each rate of grade its proper proportion as represented by the total tonnage of such class handled. For any particular division this should be done from the statistics available from that division, but taken as a whole for the system the figures may be taken from the annual report. To illustrate - the empty car mileage for several years past constitutes about 35 per cent of the total car mileage, so that we will include .35 x 925 x .327 as the factor for empty cars of 20 tons average weight. Dead freight moving in cars of about 70 tons weight constitutes about 20 per cent of the total loaded car mileage, and the balance or 80 per cent of the loaded car mileage is made up partly of dead freight of around 35 ton average car weight and the red and green ball freight. The second factor or that for 35 ton cars will then be .80 x .65 x 925 x .395, and the third factor or that for 70 ton cars will be .20 x .65 x 925 x .153. The average economical rate of grade derived from these three factors will be a .34% grade.

It should not be concluded that a .34% grade will be the economical grade for all divisions or that an average for all engines should always be used in determining the economical grade for any particular division, and the figure is presented only to show the method recommended in determining the grade to be adopted, and to further show that lower grade lines than the sometimes recommended minimum of .5% will be economical from a power standpoint. Physical characteristics of the country and the saving possible by reducing the number of trains may not make it expedient or profetable to reduce the grade to the point of economical grade. In this case great care should be exercised as to the engines used on such a division. By means of the figures given it is believed the most economical engines to be used on any of the divisions may be selected with considerable accuracy. For example, the economical grade for engine #624 is .23 per cent for empty cars and for engine #829 which can handle the same tonnage on level track at thirty miles per hour the economical grade is.40%, so that it is evident it would not be economical to use engine #624 on a division with .4 per cent grades, if engine #829 was available, nor would it be economical to use engine #829 on a division with .23 per cent grades f if engine #624 was available.

The same line of reasoning develops the fact that there would be no economy in reducing grades to an economical point for say the 1200 class engines and then operating the division with say the 400 or 500 class engines which for 35 ton cars operate economically only on a grade of about .1 per cent less. In such cases the tonnage of the 400 or 500 class engine would have to be reduced in order to operate over the higher grade line. Or, if the grade was reduced to a point economical for the 400 or 500 class engines and then operated with the 1200 class engines, the extra expense in obtaining the lower grade line would only be offsetted by a little saving in time on the road, probably inappreciable in cost. It appears evident, then, that wherever possible engines should be kept on one division, or on divisions with similar grade lines. Unfortunately it is not always possible to do this, owing to the constantly changing volume of traffic on a railroad. It also appears that the weight of engines at the present time is increasing in a much larger ratio than the weight of cars. we may, however, anticipate a time when the probable practical limit to the weight of locomotives will be reached, afetr which it will probably follow that the weight of cars will continue to increase for some time. Eventually we may expec that the economical grade line determined from the engines and cars in use today will again become the economical grade when the practical limit of weights of cars and engines has been attained. With the present practice of increasing the size of locomotives the low grade line will result in some additional expense, w ich will, however, decrease until the economical point is againe reached. Owing to the fact that the majority of shipments are one car shipments, it is believed the advance in the weight of cars will be slow, except possibly in the weight of loaded coal cars, so that the most important consideration is the increase in the weight of locomotives. The Frisco Railroad has increased the weight of its locomotives over 400 per cent since 1880 (weight is referred to as weight on the drivers), and only about 40 per cent in the last ten years, with the exception of the Mallet type of engines. The weight of box cars has increased only about 30 per cent in the last ten years, while coal cars have increased about 100 per cent in the same time.

If we continue to purchase engines similar to the 1200 class engines it will not be many years until the system will be operated with nearly all heavy engines, as every year sees some of the old light engines going to the scrap pile or sold. This seems to be justification at least on Class"A" track for using as an economical grade, a grade determined from engines of about such tractive effort as the 1200 class engines and cars of about the average weights given above. And further, if the economical grade be determined not only from the economical grade for each engine but by making a proper allowance for the value of each engine in point of tonnage, for the same percentage of average weights of cars given above, the economical grade will be practically a .4 per cent grade.

After consideration of the points mentioned, it is recommended that except in cases with a large preponderance of heavy car movement, there is no economy to be derived from reducing the rate of grade below .4 per cent, compensated for curvature.

After adopting the economical rate of grade, it is recommended the engine rating be first separated into two general classes:-

1.-Red and green ball freight or fast freight.

2.-Drag or slow freight--time freight.

For red and green ball freight a maximum speed of thirty miles per hour on level track, and a tonnage rating on that basis is recommended, such rating to be decreased where necessary so that a minimum speed of ten miles per hour may be attained on the adopted economical grade. Of course it may be impracticable to reduce the ruling grade to the economical grade, in which case the rating will necessarily be such that a speed of more than thirty miles per hour on the level is possible.

For drag or slow freight a maximum speed of twenty five miles per hour on level track and a tonnage rating on that basis is recommended, such rating to be decreased where necessary so that a minimum speed of ten miles per hour may be attained on the adopted economical grade.

The questions arise as to whether engines rated as given above will be able to start on the adopted grade if for any reason it becomes necessary to stop, and the effect of locating passing tracks on such grades. The first question will depend on two things, viz:- whether the economical grade adopted is actually the economical grade for the engine in question, and whether the difference in tractive power for the engine in question between ten and twenty-five miles per hour or thirty miles per hour is more than the starting resistance on the adopted grade. For example, assume a .4 per cent grade as the adopted grade, with a passing track to be operated in the middle of the grade. For engine 1200 hauling 35 ton cars on level grade at thirty miles per hour the rating is 2460 tons, and the economical grade .49 per cent. The available draw bar pull from the tables is given as 37432# at ten miles per hour on a .4 per cent grade. If the starting resistance allowing for slack in the train may be reduced to 8-lbs. per ton, the total resistance to starting on the .4 per cent grade would be 16-lbs. per ton, or only 2340 tons could be started on the .4 per cent grade. However if we use the full tractive effort of adhesion and full boiler pressure, usually available in starting, the draw bar pull at three or four miles per hour will be practically 43,000 lbs. and 2700 tons should be started on the .4 per cent grade, so that in actual operation we would expect this engine to start its rating on the .4 per cent grade if the bearings were warm and track conditions good. Where the tonnage was made up of 20-ton cars there would probably be no difficulty in starting. In case 70-ton cars were being handled the rating for engine 1200 should be made on the basis of a maintained speed of ten miles per hour on the .4 per cent grade, as the economical grade for the 70-ton cars is only .21 per cent, and it is evident that the engine could not handle a rating based on twenty-five miles per hour speed on level track. The rating in such case would be 3340 tons and as shown above we could not expect to start more than 2700 tons under the most favorable conditions. The second question may then be answered by saying that passing tracks should not be located in any case on the maximum grades, and should only be located on grades of such rate per cent that an engine may start its tonnage rating on the grade approaching and leaving the passing track. The best practice would of course be to locate passing tracks on level track in all cases, and when this cannot be done without great expense they should if possible be located so that there will be level track on each approach. At important junction or passing points where there is no way to avoid stopping trains or passing trains the amount which may be justifiably spent to secure such facilities may be determined by calculating the loss in train miles due to reducing the tonnage to a point where it can be handled in and out of the passing track. It is very evident that one badly located passing track at am important point on a division may increase the operating expenses a large amount by limiting the engine tonnage on the district. It is a common complaint unfortunately that tonnage has to be limited account of not being able to handle trains in and out of passing tracks. If for example engine 1200 was operating on a division hauling a large coal tonnage and the rating had to be reduced from 3340 tons to 2700 tons so that the traincould operate in and out of the passing tracks, it is apparent that it would take 20 per cent more trains to handle the business, with a resulting large increase in operating expenses.

Whether or not the economical grade line may be profitably attained in any particular piece of grade reduction work will depend on the cost of the work and the saving in train miles, or as previously stated, whether the interest on the cost of the grade reduction will be less than the saving in operating expenses. The probable increase in traffic should be considered in this connection, for it may be shown that while at the present time a .4 per cent grade is not economical, it will probably be economical in a few years with the increased traffic anticipated. For this reason it would seem good practice to recommend that where reduction to the economical rate of grade is at all profitable at the present time that no greater grade should be adopted, as the interest rate for the capital necessary will probably remain the same, while the saving in operating expenses will continue to increase, so that in a few years the increased interest charge on the first cost will be less than the increased cost of operation due to not reducing the grade to the economical grade in the first place.

Mention has been made elsewhere in this report of the relative value of the Mallet type of engine as compared to the 1200 class engines and other engines of about the same tractive power. There is given below a statement in part of a 30 days' performance test of engines 1301 and 2006 (Mallet), the test being made in December, 1911. This statement brings out several important facts in connection with the relative economy of the two classes of engines and also gives us some figures which may help to decide the very important question as to the economical size of locomotives. With engine 1301 fourteen trips were made each way between St. Louis and Newburg and with engine 2006, eleven trips were made between St. Louis and Newburg and ten trips between Newburg and St. Louis.

The results of these tests were compiled as to cost ton mileage, etc., and are given as follows:-

	Average per trip, all trips.		Total - All trips.	
Engine number,	1301	2006	1301	2006
Number of trips,	28	21	28	21
Time on road,	10-11-51	11-47-23	285- 32-00	247- 55- 00
Schedule time,	9-39-12	10-03-06		211-05-00
Number of stops,	8.8	10.7	248	225
Miles per hour actual Running time,	22.2	17.6		
Time standing,	4-53-09	5-10-09	136- 48-00	108- 33-00
Time running,	5-18-43	6-38-40	148-44 -00	139-32-00
Ratio time running to Total time,	52%	56.3%		
Aver.NO.Cars in Train	31.2	40.7		
Aver.Gr.Tons-perTrain	992.4	1484.9		
Actual ton miles,	115524	165086	3234661	3477803
Rated ton miles,	135115	218657	3783229	4591792
Ratio actual to rated ton miles,	85.5	75.5		
TerminalCoalUsed-Lbs.	1343	2132	37624	44786
Coal used standing-Lb	4110	5280	115082	110880
Coal used running-Lbs	16859	28855	472047	605955
Total coal used	22312	36267	624753	761621
Ratio coal used running to total coal	75.5	79.5		
Pounds of coal per 1000-ton miles,	193.1	219.6		
Steam pressure,	159.5	194.4		
Water used standing and running,-Gal.	16364	27770	458185	583170
Pounds of water evaporated per Lb. coal	6.50	6.77		
Equivalent evaporation from and at 212°F.	7.96	8.32		
Temperature feed water	43.6°	43.8°		

TOTAL COSTS.

Terminal Coal,	$ 1.058	$ 1.680	$ 29.63	$35.27
Coal used Std. & Run.	16.511	26.879	462.53	564.46
Water " " " "	.531	.903	14.88	18.98
Oil,Waste and Grease	.670	.880	18.76	18.48
Repairs - Labor,	2.230	5.335	62.46	112.05
Material for repairs,	.341	1.135	9.57	23.84
Turning Engine-labor,	.412	.878	11.55	18.44
Wages Engine crew,	11.368	13.604	318.32	285.69
Wages train crew,	12.100	12.738	338.81	267.51
Interest at 5-per cent	2.901	6.845	81.25	143.75
Depreciation at 3%	1.688	3.983	47.29	83.86
Total- - - - -	$ 49.810	$ 74.860	$ 1394.85	$1572.13

Cost Per 1000-Ton Miles.

	Average per trip: All trips:		Saving per 1000 ton miles.	
Terminal coal,	$ .0092	$ .0101	$ .0009	
Coal used Std.&Runng	.1429	.1628	.0199	
Water " " "	.0046	.0055	.0009	
Oil, waste and grease	.0058	.0053		$ .0005
Repairs-Labor,	.0193	.0323	.0130	
Material for repairs	.0030	.0069	.0039	
Turning engine-labor	.0036	.0053	.0017	
Wages for enginemen	.0984	.0824		.0160
Wages of train crew,	.1047	.0772		.0275
Interest at 5%	.0251	.0415	.0164	
Depreciation at 3%	.0146	.0241	.0095	
			Net=	
Total- - - - -	$ .4312	$ .4534	$ .0222	

Some of the important features of the above tests are as follows:-

The average time on the road for the Mallet engine is about 15 per cent greater than for engine 1301.

The number of stops for the Mallet engine is about 10 per cent more than for engine 1301.

The running time is greater for the Mallet engine, which is to be expected, as the average speed is about 20 per cent less than for engine 1301.

Engine 1301 hauled 85.5% of its rating while engine 2006 hauled only 75.5 per cent of its rating. The reason for this was that there was no available tonnage for filling out the rating of the Mallet engine. This is to be expected, as the experience of nearly all roads has been that it is difficult to always fill out the tonnage on the Mallet type of engines, unless the remaining tonnage is held until such time as the full rating can be secured.

It is also interesting to note that the terminal coal used agrees almost exactly with the figures given under consideration of the value of distance, given in the discussion of that subject.

The steam pressure maintained is very close to the boiler pressure for which the two locomotives are designed, showing efficient firing on the trips recorded.

The figures showing cost per 1000 ton miles do not bear out the statement made previously that the saving in fuel was one-third with the Mallet engines. It should be remembered, however, that on these trips the Mallet engine hauled only 75.5 per cent of its rating, against 85.5 per cent for engine 1301. As very nearly full boiler pressure was maintained throughout, it is reasonable to assume that the total coal used would not have been greatly different per 1000 ton miles if the full rating had been handled in each case, but in such case the cost per 1000 ton miles would decrease in favor of the Mallet engine.

If the full rating could have been handled by each engine at practically the same cost per 1000 ton miles, the Mallet engine would probably show a saving of about one-half the amount recorded as loss in the test.

In the discussion on the cost of additional engine to handle the same tonnage, there was given some figures indicating the saving in transportation expense would be offset by the increased cost of maintenance of way if these heavy engines were used. On track now laid with heavy rail and well ballasted, it is believed a limited use of the Mallet type of engines may effect some economy, provided they can be given full tonnage, but not otherwise. On the other hand all the evidence tends to show that increasing the weight of locomotives will only temporarily obviate the necessity of grade reduction work, and that such work will be rendered more costly by reason of the fact that before the heavy engines can be used, all the bridges must be rebuilt or strengthened to support them, the ballast and track superstructure must be made stronger, etc., and a great deal of this work will be lost in the process of grade reduction. A little careful calculation will show that the increased cost of maintenance of way, which may be compared to the interest charge on the engines, the greater cost of operation in many or most cases, on account of less than full rating being handled, etc., will pay interest on many times the cost of increasing the size of motive power, and often will cost more in annual interest and depreciation charges than the grade reduction would have cost. It is believed railroad managers have been slow to realize this, and are yearly losing great sums of money as a result.

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TRAIN RESISTANCE.

*** Resistance on Level Tangent. ***

The first American railway was constructed in 1830 and in 1834 had 135 miles of track in operation, running from Charleston to Hamburg, a point on the Savannah River opposite Augusta, Ga. This road was called the South Carolina Railroad, and the first locomotive to operate over it was the now famous "Best Friend." Except historically, the "Best Friend" went out of existance shortly after the negro fireman fastened down the safety valve to stop the noise of escaping steam.

The Baltimore and Ohio began construction in 1828 and the first 135 miles in operation in 1835. This road is more rightly called the Pioneer American Railroad. It was constructed to compete with the Erie Canal.

In England previous to 1830 there were some crude railways, but the general development started about the same time as in America.

The subject of train resistance soon became one of the important problems of the engineer, as evidenced by the Pampour formulas which were developed in 1834 and 1838. From that time until the present day there has been unlimited discussion and formulae presented in reference to the subject.

Most of the formulae presented have been empirical, or at least contain empirical terms, and it seems very doubtful if any other kind of a formula will be derived, or at least one simple enough for ordinary use. The reasons for this are evident in the study of the great variety of climatic conditions, the difference in design of motive power and equipment, and the different seasons of the year.

In practice the best we can do is to study the different formulae and select the one most nearly covering our own conditions, or else develop a formula of our own from tests under the actual conditions.

To show the range of authorities on the subject there is given below a summary of the important formulae, collected by a committee of the American Railway Engineering Association and presented in bulletin #84 in 1907. This collection was very thoroughly compiled and probably contains all the most carefully made tests. The committee very thoughtfully reduced the formulae to English units in order that the result might be expressed in pounds per ton of 2000 pounds, and the fractions in decimals. This allows of a comparison of various terms etc, and makes the discussion much easier to understand.

The factors used in the formulae are as follows:-

r = Resistance in lbs. per ton of 2,000 lbs.
V = Speed in miles per hour.
n = Number of cars in train.
A = Area of front of train in square feet.
a = Area of face of vehicle in square feet.
v = Speed in feet per second.
t = Weight of train in tons of 2,000 lbs.
S = Resisting surface in square feet.
L = Length of train in feet.
B = Bulk of train in cubic feet.
W = Average weight of car loaded.

AUTHOR.	FORMULA.
1.- Pampour (1834) (T+H)(F)	$r = 6.2 + \frac{0.00269\ AV^2}{t}$
2.- Pampour (1836) (T+H)(F)	$r = 5.4 + \frac{0.00269\ SV^2}{t}$
3.- Russell (1838-1845)(T+E)(P)	$r = 5.4 + 0.30V + \frac{0.0025\ AV^2}{t}$
4.- Sewell (1847)(T)(P)	$r = 5.4 + 0.06V + \frac{0.00002\ BV^2}{t}$
5.-Clark (1847) (T) (P)	$r = 5.4 + 0.00372\ V^2$
6.- Rankine (1847) (T) (P)	$r = 2.7 + 0.27\ V$
7.- Redtenbacher (1847) (T) (P)	$r = 6.2 + 0.07V - 0.00287\ \frac{(A-an)}{4}\ \frac{V^2}{t}$
8.-Deeley (1899) (T + E) (P)	$r = 2.7 + 0.00308\ V^2$
9.- Wolff (1899) (T + E) (P)	$r = 2.7 + \frac{24}{V + 3} + 0.003\ V^2$
10.- West (1899) (T + E) (P)	$r = 4.5 - 0.06\ V + 0.00363\ V^2$
11.- Laboriette (1882) (T) (F)	$r = 0 + 0.23\ V$
12.- Henderson (1904)	$r = 0.5 + 0.25\ V + \frac{50\ n}{t}$
13.- -----------	$r = 1.5 + 0.2^{o}\ V$
14.- Kock (1880)	$r = 2.0 + 0.13\ V$
15.-Engineering News (1892) (T + E)(F&P)	$r = 2.0 + 0.25\ V$
16.- Desdouits	$r = 3.0 + 0.08\ V$
17.- Baldwin Locomotive (1896)(T + E)(P)	$r = 3.0 + 0.17\ V$
18.- Vuillemin (1862)(1867)(T)(F)	$r = 3.3 + 0.16\ V$

19.-Regroy	$r = 3.7 + 0.27\ V$
20.-Ricour (1883)(T)	$r = 4.0 + 0.08\ V$
21.----------	$r = 4.0 + 0.16V$
22.-Daniel (1900)(T)(F)	$r = 5.2 + 0.07\ V$
23.-Clayton	$r = 5.8 + 0.14\ V$
24.-Holbrock (1890)(F)	$r = 6.0 + 0.14\ V$
25.-Dodd (1899)(T+H)(P)	$r = 7.0 + 0.2^{0}\ V$
26.-W. N. Smith (1904)	$r = 3.0 + 0.17\ V + \frac{0.0025\ AV^2}{t}$
27.-Ruehlmann (1880)(T)	$r = 3.6 + 0.32\ V + \frac{.0048\ AV^2}{t}$
28.-Vuillemin,etc (1862-1867)(T)E	$r = 3.6 + 0.26\ V + \frac{0.0048\ AV^2}{t}$
	Above for 20 to 31 miles.
	$r = 3.6 + 0.26\ V + \frac{0.0032\ AV^2}{t}$
	Above for 31 to 40 miles.
	$r = 3.6 + 0.45\ V + \frac{0.0021\ AV^2}{t}$
	Above for 43 miles and over.
29.-Leahy	$r = 7.5 + 0.00\ V + \frac{0.00625\ AV^2}{t}$
30.-Barbier	$r = 3.2 + 0.01\ V + 0.00236\ V^2$
Also (1897)(T)(P)	$r = 3.2 + 0.07\ V + 0.00239\ V^2$
31.-Von Borries (1904)(T)(P)	$r = 3.0 + 0.04\ V + 0.0016\ V^2$
32.-Lundie (1898)(T+H)(El)	$r = 4.0 + 0.2\ V + \frac{14\ V}{35 + t}$

33.-Lundie
Same as 32 $r = 4.0 + 0.24\ V + \frac{4.8\ V}{t}$

34.-Blood $r = 4.0 + 0.15\ V + \frac{0.30\ V^{1.8}}{t}$

35.-Sprague $r = 4.0 + 0.17\ V + \frac{0.333\ V^2}{t}$

36.-Davis $r = 6.0 + 0.13\ V + (0.315 + 0.035\ n)\ \frac{V^2}{t}$

37.-Davis $r = 3.5 + 0.13\ V + (0.347 + 0.0385\ n)\ \frac{V^2}{t}$

for freight trains 35 miles per hour.

38.-Petroff $r = 2.4 + \frac{2.12\ nV}{t} + (0.17 + 0.000684\ n)\frac{V^2}{t}$

39.-Du Bosquet (1895)(T)(P) $r = 2.0 + 0.005\ V^2$

40.-Crawford (1900)(T)(P) $r = 2.5 + 0.00214\ V^2$

41.-Barbier $r = 2.9 + 0.00414\ V^2$

42.-Wolff (1898) $r = 2.7 + 0.00357\ V^2$

43.-Desdonits $r = 3.0 + 0.00362\ V^2$

44.-Henderson (1888) $r = 3.0 + 0.00461\ V^2$

45.-Gerry $r = 4.0 + 0.005\ V^2$

46.-Forney (1892) $r = 4.0 + 0.00585\ V^2$

47.-Wellington (1878)(T+H) (F&P) $r = 4.0 + 0.00769\ V^2$, for 20 loaded box cars.

$r = 6.0 + 0.00943\ V^2$, for 40 empty box cars.

48.-Grove (1880) $r = 4.5 + 0.005\ V^2$, favorable conditions

$r = 8.0 + 0.008\ V^2$, unfavorable conditions

49.-Adams and Pettigrew $r = 5.4 + 0.00445\ V^2$

50.-Clayton $r = 5.8 + 0.00446\ V^2$

51.-Welkner $r = 6.2 + 0.004\ V^2$

52.-Horton (1894) $r = 7.1 + 0.00522\ V^2$

53.-Fink (1880) $r = 7.5 + 0.008\ V^2$, unfavorable conditions.

$r = 5.0 + 0.0052\ V^2$, favorable conditions.

54.-Pettigrew $r = 8.0 + 0.0062\ V^2$

55.-Chanute $r = 5.0 + 0.0072\ V^2 + \frac{0.27\ V^2}{t}$

56.-Wellington (1887)(T+H)(F&P) $r = 6.0 + 0.0106\ V^2 + \frac{0.64\ V^2}{t}$, empty box cars

$r = 3.9 + 0.0075\ V^2 + \frac{0.64\ V^2}{t}$, loaded box cars

$r = 3.9 + 0.0065\ V^2 + \frac{0.57\ V^2}{t}$, loaded flat cars

$r = 6.0 + 0.0083\ V^2 + \frac{0.57\ V^2}{t}$, empty flat cars

57.-Searles (1880)(T+E) $r = 4.8 + 0.00536\ V^2 + \frac{0.00048\ e^2}{e - t}\ V^2$

58.-Aspinall $r = 2.2 + \frac{V^{\frac{5}{3}}}{56.9 + 0.0311\ L}$

59.-R.H.Smith (1900)(T)(P) $r = 2.2 + \left(2.0 + 0.0035\ L - \frac{224}{112+t}\right)\frac{V^{\frac{5}{3}}}{t}$

60.-Shurtleff $r = 1.0 + 0.00\ V + \frac{90}{W}$

61.-New York Cent'l (1906)(P) $r = 1.8 + 0.11\ V$

In the above formulae the date derived is shown under the author's name. Where the resistance includes only train symbol "T" is used, for train and engine T+E, and where the resistance of train includes atmospheric head resistance T + H is used. For kind of train P = passenger, F = freight, El = elevated, E = electric.

In some of the equations no experiments were made and in other there is no record of whether experiments were made or not.

A glance over these formulae presents some interesting features, the most marked of which is that out of the 61 formulae presented only 9 are actually known to be the result of experiments or made up for freight trains, while twenty are for passenger trains and the remainder are intended either to fit any case or do not clearly indicate which. This is somewhat surprising when it is so clearly more desirable to have the correct data for freight rather than passenger train resistance.

A reference to the dates when the different equations were derived shows the subject has been receiving more or less constant attention since railroads were first constructed, but shows that the greatest number of formulae were derived during the period of greatest activity in railroad building, or between 1880 and 1900.

Nearly all of the formulae it will be noted follow one of two general forms of equations, viz:- the simple form $r = a + bV$, or the form $r = a + bV + cX^2$, the first equation containing two arbitrary constants, determined supposedly by experiment, and the second three arbitrary constants and some power of the velocity. For this reason as before stated the equations may all be considered as empirical.

The formulae disregard, of course, grade resistance and curve resistance. They also disregard acceleration or retardation due to atmospheric assistance or resistance. Hence they are intended to show the resistance of a train moving at uniform speed over a straight level track in perfect line and surface, and no wind. The first quantity usually represents the supposedly fixed or constant resistances or those which do not vary with the velocity. These are the journal and rolling friction and the friction in the moving parts of the locomotive. While it is probably true these resistances do vary somewhat with the speed, after the bearings have gotten warm and if the machine is properly lubricated the rise in these resistances is very small, as witnessed by the fact that the parts do not heat to any great extent.

The formulae in the form of the first power of the velocity were probably designed to be used for moderate velocities, while those in the form of V^2 are more applicable to all speeds. No doubt if sufficient experiments should be conducted a fair formulae could be gotten up using the first power which would cover in good shape all ordinary speeds, as the curves of increase in resistance all tend to show that the resistance does not tend to vary greatly from a straight line between about ten and sixty miles per hour.

It is evidently impossible that a single formula expressing train resistance on level tangent could apply correctly to all conditions. This is true because a train may consist of cars of several heights and widths, may be partly flat cars and partly box cars, in which case the atmospheric resistance would vary on account of the increased atmospheric resistance on the irregular form of the train. This fact has caused the development of several formulae supposed to apply to different kinds of trains, but it is of course impossible to apply such formulae to the actual making up of trains. Few of the formulae consider the variation in train load, whether the cars are empty or loaded, etc., and yet we know that the train resistance will be very much greater per ton of weight in an empty car than in a heavily loaded one.

There is also a great variation in train resistance, that is in total rolling resistance, due to the physical characteristics of a railroad. On first class track fully ballasted and in perfect surface, the rolling and journal friction will be less than where the track is soft and in poor surface and the cars are subjected to sudden changes of position, or shifting of weight on the journals and track.

These facts coupled together show the difficulty in selecting or deriving a formula which could be universally applied. What we must do then is to study the results of this long list of experimenters on the subject and find wherein we can or cannot apply the results they have obtained to our particular railroad. This application may be made harder still be the great variety of conditions with which we have to deal. For instance, in Oklahoma and the Kansas prairies we find winds with high velocities at nearly all times in the year, while in the lowlands of Missouri and Arkansas, where the right of way is often cut through dense forests, and in the hills of Alabama, we do not find winds of any extent, and of course know that the resistance will be varied accordingly.

During August 1911, Mr. A. B. Carr, Inspector Train and Station service, made a tonnage test run on the Southwestern Division between Afton and Sapulpa. The test were not made in view of determining any tonnage rating formula, but simply to determine the maximum economical train load which could be handled over that portion of the railroad with engines of different classes. The engine showing the best results of the power assigned to the division at that time was engine #711 and others of its class. This engine and class is tonnage class 20, bridge class 40, ten wheel type, 21" x 28" cylinders, Walschaert valve gear, working simple. The weights of this class engine and tractive power at slow speed are as follows:-

Weight of engine,	197,900#	
Weight of tender,	132,800#	
Total weight,	330,700#	= 165.35 tons.

Boiler pressure 200#

Tractive effort cylinders ----------	33,300 #
Tractive effort adhesion (calculated)	35,600 #
Area of front end, approximately,---	145 Sq. Ft.

In order to show the large range of values of train resistance as derived from the preceeding formulae and applied to actual conditions, this test train is taken as an example and substitutions made in each of the formulae to show the actual value which should have been expected on the test run, and comparison with the actual measured resistance by dynamometer of 6.1 pounds per ton on level track at slow speed (ten m.p.h.)

The test train was made up as follows for each of three test runs:-

Test Number	1	2	3
Tons in train	1058	1169	1126
Cars in train	27	21	58

In order to compare the resistance at different velocities two substitutions will be made in the formulae, one on the basis of uniform speed of ten miles per hour, and one on basis of uniform speed of twenty miles per hour. The reason for making this comparison is that several authors have stated the resistance to be practically uniform for speeds ranging between seven and thirty-five miles per hour, and it is desired to show the consensus of opinion is not in line with this statement.

Below is a table showing the results of the substitutions in the different formulae, giving the number of the formula, and including for sake of comparison the results indicated by the formula for passenger train as well as freight train, as certain of the authors have indicated their belief that the formula would cover any case, either freight or passenger.

Formula No.	TEST NO.1 r = 10 M.P.H.	TEST NO.1 r = 20 M.P.H.	TEST NO. 2 r = 10 M.P.H.	TEST NO. 2 r = 20 M.P.H.	TEST NO. 3 r = 10 M.P.H.	TEST NO. 3 r = 20 M.P.H.
1	6.237	6.35	6.233	6.33	6.235	6.34
2	5.437	5.55	5.433	5.53	5.435	5.54
3	8.434	11.536	8.431	11.524	8.432	11.53
4	6.150	7.21	6.11	7.06	6.33	7.92
5	5.772	6.888	5.772	6.888	5.772	6.888
6	5.4	8.1	5.4	8.1	5.4	8.1
7	7.09	8.34	7.04	8.15	7.26	9.03
8	3.008	3.93	3.008	3.93	3.008	3.93
9	4.85	5.75	4.85	5.75	4.85	5.75
10	5.463	7.15	5.463	7.15	5.463	7.15
11	2.3	9.2	2.3	9.2	2.3	9.2
12	4.27	6.77	3.9	6.4	5.6	8.1
13	3.5	5.5	3.5	5.5	3.5	5.5
14	3.3	4.6	3.3	4.6	3.3	4.6
15	4.5	7.0	4.5	7.0	4.5	7.0
16	3.8	4.6	3.8	4.6	3.8	4.6
17	4.7	6.4	4.7	6.4	4.7	6.4
18	4.9	6.5	4.9	6.5	4.9	6.5
19	6.4	9.1	6.4	9.1	6.4	9.1
20	4.8	5.6	4.8	5.6	4.8	5.6
21	5.6	7.2	5.6	7.2	5.6	7.2
22	5.9	6.6	5.9	6.6	5.9	6.6
23	7.2	8.6	7.2	8.6	7.2	8.6
24	7.4	8.6	7.4	8.6	7.4	8.6
25	9.0	11.0	9.0	11.00	9.0	11.0
26	4.734	6.537	4.731	6.525	4.732	6.529
27	6.866	10.26	6.86	10.24	6.862	10.25
28	6.266	9.06	6.26	9.04	6.262	9.05
29	7.58	7.84	7.58	7.84	7.58	7.84
30	3.536	4.44	3.536	4.44	3.536	4.44
31	3.56	4.44	3.56	4.44	3.56	4.44
32	6.13	8.26	6.11	8.23	6.12	8.25
33	6.44	8.89	6.44	8.89	6.44	8.89
34	5.51	7.02	5.51	7.02	5.51	7.02
35	5.73	7.5	5.73	7.5	5.73	7.5
36	7.31	9.0	7.31	9.0	7.31	9.0
37	Good only for thirty five M.P.H.					
38	2.92	3.2	2.92	3.2	2.92	5.5
39	2.5	4.0	2.5	4.0	2.5	4.0
40	2.71	3.36	2.71	3.36	2.71	3.36

Formula No.	TEST NO. 1 r = 10 M.P.H.	TEST NO. 1 r = 20 M.P.H.	TEST NO. 2 r = 10 M.P.H.	TEST NO. 2 r = 20 M.P.H.	TEST NO. 3 10 M.P.H.	TEST NO. 3 20 M.P.H
41	3.3	4.5	3.3	4.5	3.3	4.5
42	3.06	4.1	3.06	4.1	3.06	4.1
43	3.36	4.44	3.36	4.44	3.36	4.44
44	3.4	4.7	3.4	4.7	3.4	4.7
45	4.5	6.0	4.5	6.0	4.5	6.0
46	4.58	6.3	4.58	6.3	4.58	6.3
47	4.9	7.0	4.9	7.0	----	---
48	5.0	6.5	5.0	6.5	5.0	6.5
49	5.8	7.1	5.8	7.1	5.8	7.1
50	6.2	7.6	6.2	7.6	6.2	7.6
51	6.6	7.8	6.6	7.8	6.6	7.8
52	7.6	9.1	7.6	9.1	7.6	9.1
53	5.5	7.0	5.5	7.0	5.5	7.0
54	8.6	10.5	8.6	10.5	8.6	10.5
55	5.7	7.9	5.7	7.9	5.7	7.9
56	4.7	6.9	4.7	6.9	7.0	10.2
57	6.3	10.8	6.3	10.8	6.3	10.8
58	2.3	3.9	2.35	4.0	2.3	3.3
59	2.3	3.9	2.3	3.9	2.3	3.3
60	3.5	3.5	2.6	2.6	5.5	5.5
61	2.9	4.0	2.9	4.0	2.9	4.0

Aglance at the results obtained above shows such a confusion of values for resistance that it seems almost hopeless to make any sort of comparison of the results. For the ten mile speed the value of "r" varies from 2.3 pounds per ton to 8.4 pounds per ton, and for twenty miles speed from 3.3 pounds per ton to 11.5 pounds per ton.

By eliminating entirely the formula derived from experiments with passenger equipment and averaging the results obtained from the remainder of the formulae, the result would indicate r = 5.2 pounds per ton for ten miles per hour speed and r = 6.3 pounds per ton for a speed of twenty miles per hour.

Astudy of the length of our divisions would indicate that the speed between division points must be between ten miles per hour average and twenty miles per hour average to cover the division under the sixteen hour law. For this reason in dealing with the subject we will probably find that ten miles per hour is as slow a speed as we can ever use and probably twenty miles per hour will be as high a speed as we can profitably use. These refer to average speeds. So that in dealing with the question of train resistance, if we can derive a formula to apply in our study of reduction of grades which will cover speeds ranging between ten and twenty miles per hour without appreciable error, we can greatly simplify the problem as a whole, and it seems justifiable to assume that an average of the results obtained by all these writers should be not far from the figure which should be used. The average of the two averages would indicate "r" should be figured at 5.75 pounds per ton for ordinary speeds, which would also indicate a maximum error from the two extremes of speeds of .6 pounds per ton. However, we will probably find that most of our speeds will range around fifteen miles per hour rather than ten or twenty miles per hour, hence to be on the safe side it would appear more desirable to use a figure nearer the maximum of 6.3 or as many railroads have done, accept 6.0 pounds per ton as an all-around average figure. In making this statement it must not be understood that six pounds per ton is the accepted resistance for different speeds, for unless practically all of the experimenters are wrong in their calculations, the resistances increase with the speed. But in order to make a comparison of the performances of trains on different grades and differently loaded, we must assume some average figure on which to base the tonnage rating of various locomotives, and the figure of 6.0 pounds per ton train resistance for variations of speed within which we will probably keep in practice, assures us that no large error will be made in the more important calculations. Such an assumption as it will be seen later has no effect on the cost of the grade reduction, not on the grade lines which will be established.

In the 1911 Manual of the American Railway Engineering Association it is recommended that for comparing freight train ratings on different lines and grades the following formula be used to express resistances on level tangent for speeds between 7 and 35 miles per hour;-

$$R = 2.2\ T + 121.6\ C$$

Where

R = total resistance on level tangent.
T = total weight cars and contents in tons.
C = total number of cars.

This formula applied to the same trains before considered would indicate $r = 5.3$ pounds per ton for test #1, $r = 4.4$# per ton for test #2, and $r = 8.5$ pounds per ton for test #3.

While the record of the test trains does not indicate the number of loads and empties in each train, it is quite evident that the first two trains were principally loads, and the third train principally empties. To get at the average resistance for trains comprising both loads and empties we should take the average of the tests, which would indicate 6.9 pounds per ton for trains one and three and 6.4 pounds per ton for trains two and three, or 6.0 pounds for an average of all three, which would probably more nearly represent the average conditions.

It is also a fact that the formula recommended by the A. R. E. A. committee compares favorably with the formulae of some of the best known of the investigators, and it would doubtless be advisable to accept such formula for figuring the resistance, subject to the use of a correction factor for varying conditions of temperature track conditions, etc.

Mr. A. C. Dennis, in a letter to the American Society of Civil Engineers, states he made a long list of experiments, which proved to him that the resistance is almost constant between speeds of 7 and 35 miles per hour. Mr. Dennis says in part:-

"The experiments indicate that the resistances which increase with speed balance very nearly the decreasing journal friction for trains of box cars of 2000 tons or more, the tare of which is one-third of the gross weight on a solid frozen roadbed. The resistance for such a train is about 4.7 pounds per ton for speeds from 7 to 35 miles per hour."

In making the above statement Mr. Dennis has made a very radical departure from the ordinarily conceived notion of train resistance, and the writer believes from careful study of several hundred dynamometer tests on level track and with practically constant speed, that Mr. Dennis is very much mistaken in his statements. It is probably a fact that when a train starts out of a yard with all the bearings cold, and gradually picks up speed, that the journal friction is quite materially reduced, and in a long train, such as a 2000-ton train would ordinarily be, or as defined by Mr. Dennis, that some little time would be required for acceleration from 5 or 7 miles per hour to 35 miles per hour, and that the journal friction, which it is admitted is greater when the bearings are quite cold and the oil does not flow freely, might decrease as much as the increase in tractive resistance due to the other causes. However, the journal friction after the bearings have become warmed up will it is shown by experiment, remain almost the same regardless of the speed. It would also be incorrect to base engine rating on a uniform resistance for such variation of speed, for granting that the facts presented by Mr. Dennis may have been true for one particular train, we know positively without theory or further experiments that it requires more tractive effort to haul a train at thirty-five miles per hour than at seven. Any dynamometer test will develop that fact in a few minutes.

Probably the most comprehensive and extensive tests ever made to determine the resistance of freight cars was made jointly by the University of Illinois Engineering department at the Experiment Station, and in conjunction with the Illinois Central Railroad. The results of the test are summarized in Bulletin #43 published by the University of Illinois and edited by Mr. Edward C. Schmidt, Professor of Railway Engineering. Mr. Schmidt makes the preliminary statement in his report, which is borne out afterward, that "Train resistance varies not only with the train speed, but also with the average weight of the cars of which the train is composed. At a given speed the tractive effort required for each ton of weight of the train will be greater for example, for the train which is composed of cars of 20 tons average gross weight, then for the train composed of cars which weigh on the average 50 tons each." This fact has been quite well recognized in making tonnage ratings, but the difficulty of applying the figures to working conditions has resulted in arbitrary constants being derived in making up trains. The fact is recognized in the formula of the American Railway Engineering Association, but as stated by them the formula is only intended to be used in comparing ratings on different lines and grades, and is not intended to be used as an actual rating formula.

In order to show the great variety of trains which were tested, a statement prepared by Mr. Schmidt is given below:-

"The report deals with the results obtained from the tests of 32 ordinary freight trains, whose chief characteristics were as follows:

	Minimum.	Maximum.
Total weight, tons,-----------	747	2908
Average weight per car, tons--	16.12	69.92
Number of cars in train ------	26	89

The final curves and formulae derived from the experiments are given below. Figure A shows the relation between resistance and average car weight at various speeds, and Figure B shows the relation between resistance and speed for various weights per car. From those two curves the following formulae for car resistance are derived. The formulae are empirical to a certain extent, that is the constants are determined from the ordinates of the curves and represent as nearly as may be determined the average of the various tests.

These formulae, based as they are, on the kind of equipment in use today and under the ordinary or average class of railroad we have today, are considered to be without doubt the best information extant on the question of train resistance. The formulae follow:-

When W= 15 tons; $R = 7.15 + 0.085\ S + 0.00175\ S^2$
When W= 20 tons; $R = 6.30 + 0.087\ S + 0.00126\ S^2$
When W= 25 tons; $R = 5.60 + 0.077\ S + 0.00116\ S^2$
When W= 30 tons; $R = 5.02 + 0.066\ S + 0.00116\ S^2$
When W= 35 tons; $R = 4.49 + 0.060\ S + 0.00108\ S^2$
When W= 40 tons; $R = 4.15 + 0.041\ S + 0.00134\ S^2$
When W= 45 tons; $R = 3.82 + 0.031\ S + 0.00140\ S^2$
Whwn W= 50 tons; $R = 3.56 + 0.024\ S + 0.00140\ S^2$
When W= 55 tons; $R = 3.38 + 0.016\ S + 0.00142\ S^2$
When W= 60 tons; $R = 3.19 + 0.016\ S + 0.00132\ S^2$
When W= 65 tons; $R = 3.06 + 0.014\ S + 0.00130\ S^2$
When W= 70 tons; $R = 2.92 + 0.021\ S + 0.00111\ S^2$
Whwn W= 75 tons; $R = 2.87 + 0.019\ S + 0.00113\ S^2$

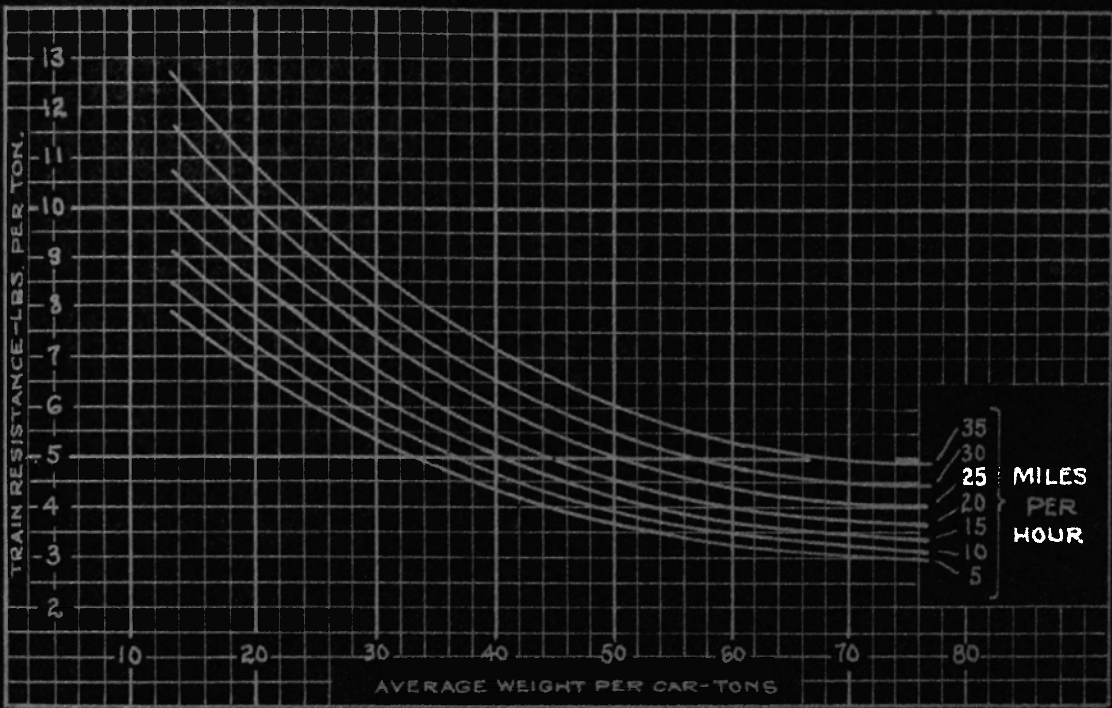

Fig. A The Relation Between Resistance and Average Car Weight, at Various Speeds.

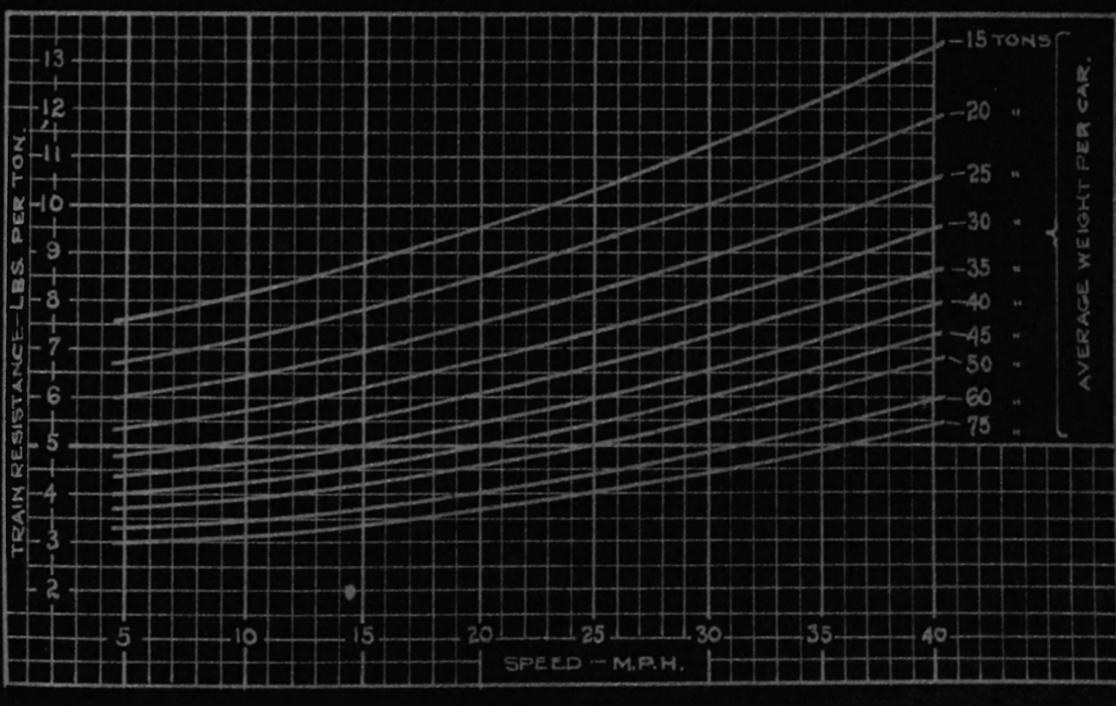

Fig. B. The Relation Between Resistance and Speed, for Various Average Weights per Car.

The results of the tests may also be expressed by the following single empirical formula in which R is expressed in both terms of "S" and "W".

$$R = \frac{S + 39.6 - 0.031\,W}{4.08 + 0.152\,W}$$

The maximum error expressed in this formula is stated to be about 9% when S = 21 and W = 55.

The final conclusion is regard to train resistance is also given as Table I, showing the resistance in pounds per ton at different speeds for different average weight of cars. Mr. Schmidt says:-

"It is sufficient to say at this point, that the results apply to trains running at uniform speed, on tangent ~~track~~, and level track of good construction, during weather when the temperature is not lower than 30 degrees F. and when the wind velocity does not exceed about 20 miles per hour." This range of conditions will cover in good shape the ordinary run of freight trains on our lines, and the formulae should be very valuable owing to the similarity between the tests conditions and the actual conditions of operation on the Frisco Lines.

If we compare this table with the results derived from the three test trains mentioned above, the results may be summarized as follows:-

Test Number	1	2	3
Tons in train	1058	1169	1126
Cars in train	27	21	58
Resistance # per ton 10-MPH	4.7	3.7	7.3
Resistance # per ton 20-MPH	5.5	4.3	8.5

Values Of Resistance At Various Speeds And For Trains Of Different Average Weights Per Car.

Table I.

Speed M.P.H.	Train Resistance – Pounds per Ton. Column headings indicate average weights per car.												
	15-T	20-T	25-T	30-T	35-T	40-T	45-T	50-T	55-T	60-T	65-T	70-T	75-T.
5	7.6	6.8	6.0	5.4	4.8	4.4	4.0	3.7	3.5	3.3	3.2	3.1	3.0
6	7.7	6.9	6.1	5.5	4.9	4.4	4.1	3.8	3.5	3.3	3.2	3.1	3.0
7	7.8	7.0	6.2	5.5	5.0	4.5	4.1	3.8	3.6	3.4	3.2	3.1	3.1
8	8.0	7.1	6.3	5.6	5.0	4.6	4.2	3.9	3.6	3.4	3.3	3.2	3.1
9	8.1	7.2	6.4	5.7	5.1	4.6	4.2	3.9	3.6	3.4	3.3	3.2	3.1
10	8.2	7.3	6.5	5.8	5.2	4.7	4.3	4.0	3.7	3.5	3.3	3.2	3.2
11	8.3	7.4	6.6	5.9	5.3	4.8	4.3	4.0	3.7	3.5	3.4	3.3	3.2
12	8.4	7.5	6.7	6.0	5.4	4.8	4.4	4.0	3.8	3.6	3.4	3.3	3.3
13	8.6	7.6	6.8	6.1	5.5	4.9	4.5	4.1	3.8	3.6	3.5	3.4	3.3
14	8.7	7.8	6.9	6.2	5.5	5.0	4.5	4.2	3.9	3.7	3.5	3.4	3.4
15	8.8	7.9	7.0	6.3	5.6	5.1	4.6	4.2	3.9	3.7	3.6	3.5	3.4
16	9.0	8.0	7.1	6.4	5.7	5.1	4.7	4.3	4.0	3.8	3.6	3.5	3.5
17	9.1	8.1	7.2	6.5	5.8	5.2	4.8	4.4	4.1	3.9	3.7	3.6	3.5
18	9.3	8.3	7.4	6.6	5.9	5.3	4.8	4.5	4.1	3.9	3.7	3.7	3.6
19	9.4	8.4	7.5	6.7	6.0	5.4	4.9	4.5	4.2	4.0	3.8	3.7	3.6
20	9.6	8.5	7.6	6.8	6.1	5.5	5.0	4.6	4.3	4.0	3.9	3.8	3.7
21	9.7	8.7	7.7	6.9	6.2	5.6	5.1	4.7	4.3	4.1	3.9	3.9	3.8
22	9.9	8.8	7.9	7.0	6.3	5.7	5.2	4.8	4.4	4.2	4.0	3.9	3.8
23	10.0	9.0	8.0	7.1	6.4	5.8	5.3	4.9	4.5	4.3	4.1	4.0	3.9
24	10.2	9.1	8.1	7.3	6.6	5.9	5.4	4.9	4.6	4.3	4.2	4.1	4.0
25	10.4	9.3	8.3	7.4	6.7	6.0	5.5	5.0	4.7	4.4	4.2	4.1	4.0
26	10.5	9.4	8.4	7.5	6.8	6.1	5.6	5.1	4.8	4.5	4.3	4.2	4.1
27	10.7	9.6	8.5	7.7	6.9	6.2	5.7	5.2	4.8	4.6	4.4	4.3	4.2
28	10.9	9.7	8.7	7.8	7.0	6.3	5.8	5.3	4.9	4.7	4.5	4.4	4.3
29	11.1	9.9	8.8	7.9	7.1	6.5	5.9	5.4	5.0	4.8	4.6	4.5	4.4
30	11.3	10.0	9.0	8.0	7.3	6.6	6.0	5.5	5.1	4.9	4.7	4.5	4.5
31	11.4	10.2	9.1	8.2	7.4	6.7	6.1	5.6	5.2	5.0	4.8	4.6	4.5
32	11.6	10.4	9.3	8.3	7.5	6.8	6.2	5.8	5.3	5.0	4.9	4.7	4.6
33	11.8	10.5	9.4	8.5	7.6	7.0	6.3	5.9	5.4	5.2	5.0	4.8	4.7
34	12.0	10.7	9.6	8.6	7.8	7.1	6.5	6.0	5.5	5.3	5.1	4.9	4.8
35	12.3	10.9	9.7	8.8	7.9	7.2	6.6	6.1	5.7	5.4	5.2	5.0	4.9
36	12.5	11.1	9.9	8.9	8.0	7.4	6.7	6.2	5.8	5.5	5.3	5.0	5.0
37	12.7	11.2	10.0	9.0	8.2	7.5	6.9	6.4	5.9	5.6	5.4	5.2	5.1
38	12.9	11.4	10.2	9.2	8.3	7.6	7.0	6.5	6.0	5.7	5.5	5.3	5.2
39	13.1	11.6	10.4	9.4	8.5	7.8	7.1	6.6	6.2	5.8	5.6	5.4	5.3
40	13.4	11.8	10.6	9.5	8.6	7.9	7.3	6.8	6.3	6.0	5.7	5.6	5.5

Note. – Above table taken from report Illinois Experiment Station Bulletin # 43. Compiled from curve diagram "B".

The average for the ten mile speeds show 5.3 pounds per ton as compared to 5.2 pounds per ton obtained by substituting in the long list of formulae, and give an average of 6.1 pounds per ton for the 20 mile speed as compared to 6.3 pounds by substitution in the previous formulae. This certainly shows that these carefully made tests tended to demonstrate the fact that the other experimenters taken as an average have been close to the mark in their reasonings and experiments. The estimated resistance for any train must at its best be only an approximation, and its use only a guide to the conditions to be anticipated under actual train movement.

The results of the University tests indicate very plainly a fact which is now recognized by all leading engineers, that train resistance is not as previously believed, a function of the velocity alone, but rather a function of both the velocity and the average car weight, loaded or empty. Wellington evidently had some such idea as evidenced by the four formulae derived by him, showing the resistance of empty and loaded box cars, and empty and loaded flat cars. His formulae would hardly apply to a mixed train, however, as it is not based on average car weights. This is a very important distinction, because if we can deduce a reasonably accurate formula to apply to tonnage rating, based on the average car weight it will be quite simple to divide our engines up into classes, and rate them regardless of the kind of a train, whether the cars are empty or loaded, etc. This in effect is what the curve resistance formulae of the University make it possible to do. It will be shown in another part of the report how this may be worked out in practice for a division.

In making comparison of different grades, it is believed that for tonnage rating of the locomotives it is correct to use the figure of 6 pounds per ton as average train resistance. The reason for this is, that the speed of the train on the ruling grade should never be below a limit of about ten miles per hour in order that the train may not atall on the grades, and six pounds per ton will be, as evidenced by all our averages, a figure which will assure that condition with minimum variations with practically any kind of ordinary train. But it is not advisable to use this figure for ruling grades, unless the trains to be compared are of the same type, for example, all merchandise trains or all coal trains. The estimated tonnage to be handled may be slightly in error by using this figure, as explained in another part of the report, but as the grade increases this error will diminish, while on very light grades the starting resistance may limit the tonnage.

In discussing the subject of momentum or velocity grades, it will be seen that the question of average car weight will become an important one as affecting the acceleration or retardation on different grades. If train resistance depends to a certain extent on car weight, it is important that in deriving a formula for momentum grades that the train resistance is figured by a formula which will allow of only the minimum error, as it is evidently not possible to state the average car weights for the different trains which may be handled. By referring to annual reports for some years previous, it is seen that the average weight of freight per loaded car is about 19 tons. The loaded car mileage is practically two-thirds of the total car mileage, which would admit of assuming the average load per car mile as two-thirds of the average load per loaded car mile or about 13 tons. The estimated average light weight of equipment used is 18 tons, though this figure cannot be more than roughly verified owing to the great number of foreign cars constantly being handled. On the basis, however, the average loaded car weight would be 31 tons. It is better, however, for rating purposes to assume a little higher per cent of loads, as the ratio of loads and empties is misleading in that the loads usually move solid, and the empties are returned in the direction of light traffic. For this reason 35 tons per car is selected as a better figure, indicating a resistance va ying from 4.8 pounds per ton to 7.9 pounds per ton for speeds varying from 5 to 35 miles per hour. Between ordinary limits of variation in loading, the resistance would not vary greatly on this assumption, probably in extreme cases being less than 1000 pounds total. With our heaviest engines this would allow of a maximum error in rating of three per cent and in the light engines a maximum error of about six per cent on level tangent track.

The effect on operating expenses should be much smaller than this even, as the error is more likely to occur in trains of empty cars than in trains of loads, as it is seen from the curves that the resistance per ton decreases with the increased average weight of cars. In the three test cases the average weights of the loads were, test #1, 40 tons per car; test #2, 50 tons per car; test #3, 80 tons per car. The total resistance in test one, using the 35-ton average basis would be 5501# on level tangent at ten miles per hour speed. Using the actual or 40-ton basis the total resistance would for the same speed be 4972# or 529# less. The calculated tractive effort of engine #711 was 35,600#, or the 529# error would be less than one per cent of the theoretical loading on a level tangent. If this error occured on a division all level tangent, the difference in the number of cars hauled would be about three thirty-ton cars, but if it occurs on a division where there is a ruling one and a half per cent grade, it would make a maximum error of less than one loaded car. For grades between, the error would lie between those limits. Carrying out the figures for the other two tests, it will be found the total resistance for test two on the 35-ton average basis is 6079# and on the actual 50-ton basis is 4676#, an error of 1403# in tractive effort. Test three on the 30-ton basis shows a total resistance of 5855# and 8219# on the actual weights, an error in the opposite direction of 2364#. This shows that on empty trains the tonnage rating would probably be too great and on loaded trains too light. In practice this will cause no operating loss so far as the empty car train is concerned, as the distribution of the cars demands that for a car run in one direction another shall be run in the opposite direction whether loaded or empty. As the engine must also be returned, the empty train mileage can never exceed the loaded train mileage and it does not make any appreciable difference in operating expenses as already shown, whether the train is run in two sections or one, if the engine mileage is not increased. All of which means, that if all the traffic in one direction was empty box cars and all in the other direction loaded cars, the resistance of the loaded cars is the point to be determined, and the empties will take care of themselves. There is only one exception to this case. If the ruling grade is against the empties instead of the loads, the question on locomotive rating for the empties may become important, but it is very seldom the case that the difference in grades will be so great and the number of empties compared to loads so great, that this unbalanced condition will exist. The curves diverge rapidly as the speed increases, showing that the error would increase with the speed if the average weight is incorrectly assumed. This is actually true as may be found by carrying out the figures in the three tests for a speed of twenty or thirty miles per hour.

In actual rating, however, we may assume as near the average tonnage as possible and rate on that basis, and then add or subtract from this rating a given per cent for variation in loading. On some divisions the error will be so small that it may be neglected, this being especially true where the total resistance is considerably greater than the level tangent resistance, as a division with ruling grades of one per cent or greater. On a level division the correction is important but should only be attempted to the nearest five tons. For example it was found in test one, that the error was about three cars on level track, but less than one car on a one and one half per cent ruling grade. In test three the error was much larger, amounting to about 17 cars of 20 tons each on level track, and to three cars of 20 tons on the assumed one and a half per cent ruling grade. These figures also bring out the fact that the rating may be corrected more readily for each division, knowing its ruling grade, than to attempt to correct the rating in a general way for the different average weights of cars.

For the purposes indicated in this report, the assumption will be made that the average car weight is 35-tons, and that the train resistance on level tangent is expressed by the formula:-

$$R = 4.49 + 0.06\ S + 0.00108\ S^2$$

The further assumption will be made for the purpose of comparing the number of trains necessary to handle a given traffic, that the level tangent resistance is six pounds per ton, corresponding for the 35-ton cars to a speed of approximately twenty miles per hour, which is about the average speed for which the engines should be loaded on level track.

As a comparison of the results which will be obtained by using the formula selected with other well known and much used formulae, there is given below a statement of the resistance as figured by these formulae, on the a assumption of a train of 30 loaded box cars of 35-tons average weight running at 20 miles per hour. The level tangent resistance per ton by the different formulae would be as follows:-

Engineering News -- $r = 2.0 + .25V = 7.0$ pounds.

Baldwin Locomotive- $r = 3.0 + .17V = 6.4$ pounds.

Wellington -- -- -- $r = 3.9 + .0075\ V^2 + \dfrac{0.64\ V^2}{t}$
$= 7.1$ pounds per ton.

Illinois Exp. Sta. -$r = 4.49 + 0.06\ S + 0.00108\ S^2$
$= 6.1$ pounds per ton.

The recommended formula of the A.R.E.A. would indicate the resistance for such a train to be,

$R = 2.2\ T + 121.6\ C = 5.7$ pounds per ton.

The question naturally arises as to whether or not there will be large errors in operation caused by the use of one of these formulas instead of another. The question was practically answered in showing the errors in the rating of engines, which would be obtained by incorrect assumption of car weight, and it may be said simply, that the eror will be larger on level track than on the grades. As the grades are the things to be reduced, and as the minimum error occurs on the grades, the rating error will ordinarily be very small. It must also be remembered that it is only the theoretical rating which will be affected. Actually the operating officials will increase or decrease the load according to what they find the engine can haul. The error introduced then, will be in the amount of saving to be affected by any grade reduction, for it is principally in the matter of grade reduction that the error will be appreciable. As previously stated, if the cost of the reduction is such that no saving of moment is to be expected, it is seldom advisable to make such reduciton, so that a slight error in the theoretical figure should not in the end affect the question of whether or not the money will be spent.

CURVE RESISTANCE.

The resistance to uniform motion of a train on a curved track is not susceptible of accurate mathematical calculation. Experiment and experience are the only means of obtaining anything like a true value. Attempts have been made to determine the theoretical resistance based on the weight and co-efficient of friction between the wheels and the rails, acting through the estimated lateral slippage of the wheel. The results have indicated about .4 pound per ton for a one degree curve with a similar increase or decrease in proportion to the degree of curve. To this quantity is usually added an arbitrary amount varying from .5 pound to one pound per ton on one degree curve, supposed to represent the side thrust or friction of the flange of the wheel against the rail. Actual experiments have indicated that the curve resistance for light curves is somewhat greater relatively than for heavy curves, a fact which is hardly borne out in the theoretical calculations.

It will not be attempted here to show the theoretical calculations, but rather to determine the figure which experience has shown to represent most accurately curve resistance as actually found by experi-ment. The length of wheel base has been found to affect the amount of the curve resistance, which is to be expected, as it is evident the lateral slippage of the wheel will be greater on a longer wheel base because the angle between the tangent to curve at point of contact and the axial line of the trucks will necessarily be greater. For this reason the curve resistance as affecting locomotives will be somewhat greater than for cars, as the wheel base is usually longer. However, the variation is not great and is ordinarily neglected. The justification of this lies in the fact that the increase in resistance due to longer wheel base does not vary directly with the degree of curvature, but as the degree of curvature increases the relatively greater resistance decreases, so that the total resistance is only a small per cent greater on a heavy curve than on a light one.

It has been commonly accepted that 0.8 pound per ton per degree of curve represents the average maximum curve resistance for American made cars. This would represent the amount of resistance due to a .04 per cent grade, as will be seen later, and compensation for curvature is usually made on such a basis. The American Railway Engineering Association Manual for 1911 recommends compensation of curvature at .035 per cent per degree of curve, representing a curve resistance of .7 pounds per ton per degree. There was considerable discussion in the Society and much opposition to selecting .035 instead of .04. It would seem safer to select the higher figure as the quantity is more or less uncertain at best, and .04 will be used in the calculations in this report and is recommended for use elsewhere.

In the study of grade reduction propositions, the first step in the inspection of the profile should be to lay a corrected grade line over the actual grade line, showing the grades as compensated for curvature, unless it be known that the line is compensated, and the amount of same.

After this is done the compensated grade line should be used and the curvature may then be disregarded. In laying the final profile, which may or not be a velocity profile, the grades should of course be compensated for the curvature that may exist. Where a curve exists on level track, it may evidently be regarded as a grade, which in some cases may be operated as a velocity grade. This condition exists in many places on the lines of the Pennsylvania Railroad in the East, and in some cases becomes a limiting feature of the tonnage rating.

For convenience there is given Table II showing the resistance per ton and the necessary compensation for curvature for each fifteen minutes, for curves between 00 deg. and 14 degrees. This covers the ordinary range of curvature, and as the grade should not be laid closer than one thousandth, the compensation may be selected from the table to the nearest fifteen minutes of the degree of curve.

GRADE RESISTANCE.

The resistance to uniform motion due to grade may be calculated with mathematical precision. It is evident that if the train ascends or descends a grade on straight track, there can be only two resistances to be overcome, one the resistance already considered, or that due to the friction, and the other caused by the force of gravity. The first resistance already having been calculated, the remaining energy to be expended is that in raising the

Resistance and Compensation for Curvature.

Formula R = 0.8 Lb. Per Ton Per Degree.

Deg. Curve		Minutes 0'	15'	30'	45'
0	Resistance # Per Ton	0.0	0.2	0.4	0.6
	Compensation = Equiv. Grade	0.0	.01	.02	.03
1	Resistance # Per Ton	0.8	1.0	1.2	1.4
	Compensation = Equiv. Grade	.04	.05	.06	.07
2	Resistance # Per Ton	1.6	1.8	2.0	2.2
	Compensation = Equiv. Grade	.08	.09	.10	.11
3	Resistance # Per Ton	2.4	2.6	2.8	3.0
	Compensation = Equiv. Grade	.12	.13	.14	.15
4	Resistance # Per Ton	3.2	3.4	3.6	3.8
	Compensation = Equiv. Grade	.16	.17	.18	.19
5	Resistance # Per Ton	4.0	4.2	4.4	4.6
	Compensation = Equiv. Grade	.20	.21	.22	.23
6	Resistance # Per Ton	[redacted]	5.0	5.2	5.4
	Compensation = Equiv. Grade	[redacted]	.25	.26	.27
7	Resistance # Per Ton	5.6	5.8	6.0	[redacted]
	Compensation = Equiv. Grade	.28	.29	.30	[redacted]
8	Resistance # Per Ton	6.4	6.6	6.8	7.0
	Compensation = Equiv. Grade	.32	.33	.34	.35
9	Resistance # Per Ton	7.2	7.4	7.6	7.8
	Compensation = Equiv. Grade	.36	.37	.38	.39
10	Resistance # Per Ton	8.0	8.2	8.4	8.6
	Compensation = Equiv. Grade	.40	.41	.42	.43
11	Resistance # Per Ton	8.8	9.0	9.2	9.4
	Compensation = Equiv. Grade	.44	.45	.46	.47
12	Resistance # Per Ton	9.6	9.8	10.0	10.2
	Compensation = Equiv. Grade	.48	.49	.50	.51
13	Resistance # Per Ton	10.4	10.6	10.8	11.0
	Compensation = Equiv. Grade	.52	.53	.54	.55
14	Resistance # Per Ton	11.2	11.4	11.6	11.8
	Compensation = Equiv. Grade	.56	.57	.58	.59

Table II.

train on the grade. The resistance to be thus overcome due to the vertical distance through which the train must be lifted, can be expressed as an equation expressing work. The energy expended in lifting the train will be represented by the weight of the train, W, acting through the vertical distance X, or the energy expended thereby = WX. Since work = force times distance, we can write the equation,

$$WX = RgL$$

where Rg = increment of the rise, and L the length of the rise, or the length of the grade. To be mathematically correct, the distance L will be the distance measured horizontally. For all practical purposes, the resultant of the two forces, horizontal and vertical, will be the same length as the horizontal component. On a mile of one per cent grade, the length of the track measured either horizontally or on the inclined slope is less than a foot different. We may then transpose the equation and say,

$$Rg = \frac{WX}{L}, \text{ or}$$

since $\frac{X}{L}$ = rate of grade, which is commonly expressed in foot rise per 100 foot distance, we may express the resistance due to grade per ton, or per 2000 pounds, as,

$$Rg = \frac{2000 \text{ times rate per cent grade}}{100}$$

or, Rg = 20 times rate per cent grade (in lbs.)

The error in this calculation is about .02 of one per cent on a two per cent grade, a quantity which is negligible. On grades less than two per cent the error will be correspondingly less.

The expression of the resistance to be overcome in ascending a grade is evidently the expression of the force which will tend to accelerate the speed in descending a grade, so the force of 20 pounds per ton on a one per cent ascending grade which would be a retarding force, will also be a measure of the accelerating force on a one per cent descending grade. If the resistance due to uniform motion on a level track is six pounds per ton, it is evident that on a descending one per cent grade there would be an excess available force tending to accelerate the motion of 14 pounds per ton, independent of the tractive effort from the engine. This force will actually accelerate the motion until the resistance due to friction and velocity becomes 20 pounds per ton, at which point the object will cease to be accelerated and move with uniform velocity. We may readily determine the effect of this accelerating or retarding force due to grade resistance as it remains the same regardless of the velocity.

ACCELERATED MOTION.

* * * * * *

As in the case of computing the resistance due to grade, it is also mathematically possible to calculate the resistance to acceleration, or the force required to accelerate a body from one speed to another. Application is made of the laws of inertia and other simple principles of mechanics. A great deal has been written on the subject, but the question is usually considered from the same view point, with only slight differences in the method of arriving at the results. Mr. William G. Raymond, of the A. S. C. E., and Professor of Civil Engineering at the University of Iowa, has probably presented the question as simply and compactly as any one who has ever written on the subject, and the portion of his work entitled "Railroad Engineering", which deals with acceleratdd motion, is reprinted verbatum below:-

"Accelerated Motion:- The resistance offered to change of speed is a definite quantity that can be determined with precision. The determination depends on certain simple principles of mechanics which will be stated."

"By the property of inertia, all bodies tend to stay in that condition of motion in which at any instant they may be. An accelerating, reatrding, or deviating force must be applied to change the condition of motion as to velocity or direction."

"It is known that a constantly applied force of given magnitude will produce a uniformly changing condition of motion on any given mass. The rate of change is called the acceleration and may be positive or negative (retardation). It is known also that the acceleration of a given mass is proportional to the magnitude of the constant unbalanced force acting. Thus, if w be the weight of a body, that is, the measure of the force of gravity acting upon it, and g be the acceleration due to gravity, and if P be any other force applied to the body, the acceleration, a, produced by P, will be given by,--

$$\frac{a}{g} = \frac{P}{w}, \text{ or}$$

$$a = \frac{P}{w} g \qquad (1)$$

from which the force P necessary to produce the acceleration, a, in a body of given weight, w, is,

$$P = \frac{wa}{g} \qquad (2)$$

This force P may be considered the resistance to change of velocity for the rate of change, a."

"Under the influence of the force of gravity the velocity of a falling body increases g feet per second, g having a value varying with the distance from the center of mass of the earth and with latitude, but usually assumed for mechanical problems as 32.16 lbs. If the body starts from rest, it will have a velocity of g feet at the end of the first second; its average velocity for the first second will be g/2, w ich will also be the space covered in the first second. At the end of t seconds, the velocity will be tg feet per second, the average velocity will have been tg/2, and the space passed over will therefore be $tg/2 \times t = t^2g/2$. If v be velocity in feet per second, t be time in seconds, and h the space or height of fall,

$$v = gt \qquad (3)$$

$$h = \frac{gt^2}{2} \qquad (4)$$

since from (3) $t = v/g$, substitution in (4) gives

$$h = \frac{v^2}{2g} \qquad (5)$$

"Perfectly analogous to these equations, if P be a force acting on a body and producing an acceleration of <u>a</u> feet per second, for t seconds, covering a space of <u>l</u> feet--

$$v = at \qquad (6)$$

$$l = \frac{at^2}{2} \qquad (7)$$

$$l = \frac{v^2}{2a} \qquad (8)$$

"If a body be uniformly accelerated in a distance <u>l</u> feet from rest to a velocity of v feet per second, the acceleration from (8) is --

$$a = \frac{v^2}{2l} \qquad (9)$$

and the force P necessary to produce this acceleration given by substituting for <u>a</u> in (2), its value from (9), is

$$P = \frac{wv^2}{2\,g\,l} \qquad (10)$$

If the velocity is expressed in miles per hour, S, then

$$v = \frac{5280\ S}{3600}$$

and

$$P = \frac{w}{2gl} \times \frac{(5280\ S)^2}{(\ 3600\ )}$$

and if the weight is expressed in tons W, of 2000 pounds,

$$W = 2000\ w$$

and

$$P = \frac{66.9\ WS^2}{l} \qquad (11)$$

"Train Acceleration:- If a train be the body, P is the tractive effort in pounds to be exerted by the locomotive on a train of W-tons including the locomotive, to produce the velocity S miles per hour in a distance l-feet, starting from rest."

"Not only is the train given a velocity of translation, but the wheels are given a velocity of rotation, requiring P to be larger than indicated by the forgoing expression, by an amount depending on the relative masses os car and wheels, the pattern of the wheels and the velocities. For any given set of conditions the addition of P may be determined by comparing the energy required to accelerate the car wheels in their motion of translation to the car as a whole. No great precision can be attempted for a general formula. The increase of P may be as little as 2 1/2 per cent, and it may be as high as 6 or 8 per cent over that given by equation (11). Adopting 4.63 per cent for simplicity of result:-

$$P = 70\ \frac{S^2}{l}\ W \qquad (12)$$

This force P must be in excess of the forces necessary to overcome all other resistances."

"It is probable that no train is uniformly accelerated from rest to any given velocity it may attain, because from a velocity of 0-plus to 5 or 6 miles an hour the pull an engine exerts is nearly constant and is the tractive effort of adhesion, while the resistances to motion rapidly decrease, leaving an increasing portion of the tractive effort for acceleration. When the velocity of 5 or 6 miles is exceeded, the resistances to motion slowly increase, the tractive effort decreases, and there results a decreasing force available for acceleration, decreasing somewhat more rapidly than in proportion to the increase of velocity."

"If the velocity is to be increased from S_1 miles per hour to S_2 miles per hour, the force required is

$$P = 70 \frac{W}{l} (S_2^2 - S_1^2) \qquad \text{(A)}$$

"If the force be known, and it is desired to determine the distance required to increase the velocity from S_1 to S_2 miles per hour,

$$l = 70 \frac{W}{P} (S_2^2 - S_1^2) \qquad \text{(B)}$$

"If the distance and available force are known, and it is desired to know how great a load can be carried with the required acceleration, A and B as the case may be, is solved for W, giving

$$W = \frac{P\,l}{70(S_2^2 - S_1^2)} \qquad (C)$$

"If W, P, l and S_1 are known, and S_2 is desired, A or B is solved for S_2 giving--

$$S_2 = \pm\sqrt{\frac{Pl}{70\,W} + S_1^2} \qquad (D)$$

"In determining l, since P can never be constant, nor even approximately constant, through any considerable change in speed, it is not uncommon to find l for a change in speed of one mile per hour, using successively S_1, $S_1 + 1$, $S_1 + 2$, etc. as initial speeds, until the required change is reached, when the sum of the several values of l will be the distance required. If $S_2 = S_1 + 1$, equation (B) becomes--

$$l = 70\,\frac{W}{P}\,(2\,S_1 + 1) \qquad (E)$$

"The load W in any problem likely to arise would be known or estimated. The available tractive effort P must be estimated by subtracting from the estimated effort of the locomotive, the resistances due to such grade as the train may be on, and the train resistance. Equation (A) gives the resistance due to acceleration, or change of speed, or what is the same thing, the force necessary to produce acceleration."

A few simple applications of these formulae to show the practical application will be of value, as they will be used extensively in the practical determination of velocity or momentum grades, which will be discussed later. Consider for example a train of 500 tons total weight on a straight level track, pulled by a locomotive capable of exerting any required drawbar pull or tractive effort. If for example we wish to know what force will be necessary to increase the velocity of this train from 10 tp 20 miles per hour in 5000 feet, we may substitute for P in equation (A), then

$$P = 70 \frac{500}{5000} (20^2 - 10^2) \quad , \text{ or}$$

$$P = 2100 \text{ lbs.},$$

or expressed in pounds per ton of train, the required accelerating force would be 4.2 pounds per ton. If the available tractive effort for acceleration was greater than 4.2 pounds per ton, it is evident the required speed would be obtained in less than 5000 feet. If the available tractive effort is known, substitution may be made in equation (B) and the distance required for the acceleration determined.

In writing equation (E) the point Mr. Raymond wishes to bring out is that P varies with the speed, because the tractive effort of every locomotive decreases with the speed above a speed of about ten miles per hour. The method he suggests may be somewhat simplified by assuming P as the average available tractive effort between the desired speeds. This should not be done, however, for speeds less than 10 miles per hour. The error in this assumption is negligible, and will be much less than the error in calculating the tractive effort, which as previously seen depends on a great variety of conditions. Below ten miles per hour speed the tractive effort may be considered as constant, though it is probably greatest at a speed of four or five miles per hour.

--*-*-*-*-*-*-* VELOCITY HEAD. *-*-*-*-*-*-*-*-*

If we should assume in the example given just above that the tractive power was only great enough to overcome the frictional resistance on the leveltrack at a speed of v-miles per hour, and that the train encountered a grade of indefinite length, it is evident that the height the train would be lifted above the level would be expressed by the equation (5)

$$h = \frac{v^2}{2g}$$

Conversely if the height be known it is evident the velocity may be computed. However, this expression does not take cognizance of the distance. We may however, substitute $\frac{5280\ S}{3600}$ for v in the equation, which will then give an expression for the height and the distance. Making the substitution, the equation becomes,

$$h = .03344\ S^2$$

However, as in the case of accelerated motion, we should add a given average per cent for the kinetic energy of the rotating wheels. The same figure, 4.63% should apply here. The corrected formula, which we may call the velocity head formula will then be,

$$h = .035\ S^2$$

The application of the use of this formula and its importance in determining velocity grades will be more fully set out under the head of velocity grades.

As an illustration of the fundamental use of the formula, suppose the speed of the train at the instant the grade was encountered was twenty miles per hour. Its velocity head would then be 14.00. If the grade was a one per cent grade, the train would be carried 1400 feet up the grade before it would lose its velocity and stall. This of course is on the original assumption that the tractive force was not increased or diminished but remained the same on the grade as at the instant it reached the grade. Suppose the grade was only 500 feet long, in which case five feet of velocity head would have been lost and the train would still have in reserve nine feet of velocity head. We may then solve the equation for S and it will be found that the velocity has been reduced to 16.1 miles per hour. If at this point a level grade is encountered and the tractive effort is not increased the train will continue at a speed of 16.1 miles per hour.

Conversely, if the train encounters a down grade of one per cent while running at twenty miles per hour, we may calculate its speed at any point on the grade. Assume the grade to be 1000 feet long, or a drop of 10 feet. The velocity head at 20 miles per hour is 14.00. If the train drops 10 feet the velocity head will be 24.00. We may then solve for S and it will be found the train is running at a speed of 26.2 miles per hour.

These two examples show briefly the value of the formula and its application in the laying out of momentum or velocity grades. A great many other factors must be considerd, however, such as the available tractive power, the grade and curve resistance, the desirable speed limits, etc., all of which will be taken up in the more extended discussion of the subject. On account of the frequent use of the formula the velocity heads for different speeds are often calculated and tabulated for convenience. There is attached here a table given as Table III which is a reprint of the table prepared by Prof. Raymond. Othere writers have assumed slightly different values for the kinetic energy of the rotating wheels. Prof. Webb assumed 5%, which reduces the formula to $h = .03511\ S^2$, the same as used by Mr. Berry on the grade reduction work on the Union Pacific Railroad. Mr. Wellington assumed 6.14%, which reduces the formula to $h = .0355\ S^2$. For speed up to 50 miles per hour there is practically no difference in the velocity heads figured from any one of these formulae. For ordinary purposes about fifty miles per hour is as high a velocity as will be used for passenger trains and for the

TABLE III.

LOCITY HEAD IN FEET FOR SPEED IN MILES PER HOUR.

FORMULA $h = .035\,S^2$

0.0	0.1	0.2	0.3	0.4 (Tenths)	0.5	0.6	0.7	0.8	0.9	Speed M.P.H.
0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.03	0
0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.13	1
0.14	0.15	0.17	0.19	0.20	0.22	0.24	0.26	0.27	0.29	2
0.31	0.34	0.36	0.38	0.40	0.43	0.45	0.48	0.51	0.53	3
0.56	0.59	0.62	0.65	0.68	0.71	0.74	0.77	0.81	0.84	4
0.87	0.91	0.95	0.98	1.02	1.06	1.10	1.14	1.18	1.22	5
1.26	1.30	1.35	1.39	1.43	1.48	1.52	1.57	1.62	1.67	6
1.72	1.76	1.81	1.87	1.92	1.97	2.02	2.08	2.13	2.18	7
2.24	2.30	2.35	2.41	2.47	2.53	2.59	2.65	2.71	2.77	8
2.84	2.90	2.96	3.03	3.09	3.16	3.23	3.29	3.36	2.43	9
3.50	3.57	3.64	3.71	3.79	3.86	3.93	4.01	4.08	4.16	10
4.24	4.31	4.39	4.47	4.55	4.63	4.71	4.79	4.87	4.96	11
5.04	5.12	5.21	5.29	5.38	5.47	5.56	5.65	5.73	5.82	12
5.91	6.01	6.10	6.19	6.28	6.38	6.47	6.57	6.66	6.76	13
6.86	6.96	7.06	7.16	7.26	7.36	7.46	7.56	7.67	7.77	14
7.87	7.98	8.09	8.19	8.30	8.41	8.52	8.63	8.74	8.85	15
8.96	9.07	9.18	9.30	9.41	9.53	9.64	9.76	9.88	10.00	16
10.11	10.23	10.35	10.47	10.60	10.72	10.84	10.97	11.09	11.21	17
11.34	11.47	11.59	11.72	11.85	11.98	12.11	12.24	12.37	12.50	18
12.64	12.77	12.90	13.04	13.17	13.31	13.45	13.58	13.72	13.86	19
14.00	14.14	14.28	14.42	14.57	14.71	14.85	15.00	15.14	15.29	20
15.44	15.58	15.73	15.88	16.03	16.18	16.33	16.48	16.63	16.79	21
16.94	17.10	17.25	17.41	17.56	17.72	17.88	18.03	18.19	18.35	22
18.52	18.68	18.84	19.00	19.17	19.33	19.50	19.66	19.82	19.99	23
20.16	20.33	20.50	20.67	20.84	21.01	21.18	21.35	21.53	21.70	24
21.88	22.05	22.22	22.40	22.58	22.76	22.94	23.12	23.30	23.48	25
23.66	23.84	24.03	24.21	24.40	24.58	24.77	24.95	25.14	25.33	26
25.52	25.70	25.90	26.09	26.28	26.47	26.66	26.86	27.05	27.25	27
27.44	27.64	27.83	28.03	28.23	28.43	28.63	28.83	29.03	29.23	28
29.44	29.64	29.84	30.05	30.25	30.46	30.67	30.88	31.08	31.29	29
31.50	31.71	31.92	32.13	32.35	32.56	32.78	32.98	33.20	33.42	30
33.64	33.85	34.07	34.29	34.51	34.73	34.96	35.18	35.40	35.62	31
35.84	36.06	36.29	36.52	36.74	36.97	37.19	37.42	37.65	37.88	32
38.11	38.34	38.58	38.81	39.05	39.27	39.51	39.75	39.98	40.22	33
40.46	40.70	40.94	41 .8	41.42	41.66	41.90	42.14	42.38	42.63	34
42.87	43.12	43.37	43.61	43.86	44.11	44.36	44.61	44.86	45.11	35
45.36	45.61	45.87	46.12	46.38	46.63	46.88	47.14	47.40	47.66	36
47.91	48.18	48.43	48.70	48.96	49.22	49.48	49.74	50.01	50.28	37
50.54	50.81	51.08	51.34	51.61	51.88	52.16	52.42	52.69	52.96	38
53.24	53.51	53.7[illegible]	54.06	54.34	54.61	54.89	55.17	55.44	55.72	39
56.00	58.84	61.74	64.72	67.76	70.88	74.06	77.32	80.64	84.02	40
87.50	91.03	94.64	98.31	102.06	105.77	109.75	113.72	117.74	121.83	50

freight trains the speed should not exceed 30 miles per hour as safety requires that freight trains shoupd ordinarily not exceed this limit. At 90 miles per hour the available tractive effort at the tender becomes practically nothing in most locomotives, as the total capacity of the boiler is needed to overcome the internal resistance in the engine. Fast passenger engines with very large drivers are an exception to this in some cases. The maximum error in the table by the different assumptions as to the kinetic energy of the rotating wheels is 1.2 feet velocity head at 50 miles an hour, ~~considering the maximum speed for freight service,~~ corresponding to 120 feet of one per cent grade. Considering the maximum speed for freight service, the maximum error would be .45 foot velocity head, corresponding to 45 feet of one per cent grade. As we have assumed the lowest of any of the values for h in our calculations, we will evidently be on the safe sidd, and the only error of moment will be in possibly making a slightly greater reduction of some summit or sag, than is absolutely necessary, but which nevertheless may not be a cause for loss in operation as the practical train load may be increased accordingly.

VELOCITY OR MOMENTUM GRADES.

In the discussion of accelerated motion certain formulae were derived showing the distance a train would travel in accelerating speed from one velocity to another with a given accelerating force, provided the tractive resistance remained uniform, and conversely the force required to make a certain increase in velocity in a given distance. The forces available for acceleration of a train can come from only two sources, neglecting atmospheric conditions. First from the engine, second by reason of a descending grade. The accelerating force available from the engine, as has already been shown, depends on the type of locomotive, the speed at which it may be running, and the character of the train it is pulling. The accelerating force due to a descending grade is evidently 20 pounds per ton on a descending one per cent grade, as the resistance due to an ascending one per cent grade is 20 pounds per ton.

Consider for a moment that a train has acquired a velocity of ten miles per hour on a level track but that the engine is still capable of exerting a tractive force of 20 pounds per ton of train in addition to the resistance being overcome at a speed of ten miles per hour. If an ascending grade of one per cent be encountered and the 20 pounds per ton available force is exerted the train will continue up the one per cent grade at a uniform speed of ten miles per hour. If only level track be encountered and the excess tractive effort be applied, it is evident the speed will be accelerated until the tractive effort and the train resistance balance each other, in which case the train will cease to gain speed and will move with uniform velocity. The same will be true if the 20 pounds excess force becomes available by reason of the train descending a one per cent grade. In case the available excess force be developed from the engine and the speed be accelerated on the level track, the velocity acquired will be the same.

From the discussion of train resistance and locomotive tractive power, it has been shown that the train resistance increases and the drawbar pull decreases as the speed increases above ten miles per hour, or as the speed decreases to ten miles per hour from some greater speed, the train resistance decreases and the draw bar pull increases. If the train encounters a descending one per cent grade the effect is the same as adding 20 pounds per tons to the drawbar pull, which 20 pounds however remains constant regardless of the speed. Or if the train encounters an ascending one per cent grade, the effect is the same as decreasing the draw bar pull 20 pounds per ton, regardless of the speed. So long then as the drawbar pull is virtually in excess of the train resistance the speed will be accelerated, and so long as the drawbar pull is virtually less than the train resistance the speed will be retarded, amd whenever the two forces balance each other the speed will remain uniform.

In practice we load our engines so that they can make the minimum safe maintained speed on the ruling grade. If the ruling grade be one per cent the engine is given the maximum load it can haul at ten miles per hour maintained speed on a one per cent grade. Then on level grade or descending grades or grades less than one per cent, the train can evidently be hauled at a greater speed than ten miles per hour, as there will be an excess force available for acceleration. Assume that on some lesser grade the velocity be accelerated to thirty miles per hour, the maximum safe speed recommended for freight trains. As explained in discussion of "velocity head" there is then stored up sufficient force or energy to raise the train vertically through a certain distance or as explained the train has a certain velocity head. At thirty miles per hour from Table III, it is found the velocity head is 31.50 feet. Or in other words, if the train resistance and all other resistances be neglected for a moment, the stored up energy would raise the train 3150 feet on a one per cent grade or 1575 feet on a two per cent grade before it came to rest. But if we consider all the forces acting and the train encounters the one per cent grade, the speed would gradually retard to ten miles per hour and then remain uniform. On the two per cent grade the decrease in train resistance and the increase in drawbar pull would change with the speed just the same as in climbing the one per cent grade, but the retarding force due to the grade or the virtual decrease in draw bar pull would be 20 pounds per ton more than in climbing the one per cent grade. Hence the velocity head will be lost much quicker and the train will not run as far on the two per cent grade before the speed drops to ten miles per hour as it did on the one per cent grade.

The determination of the distances traversed in accelerating or retarding the speed between different limits and on various grades is the problem of velocity or momentum grades. The common expression of "taking a run at the hill" means simply taking advantage of the virtual increase in drawbar pull at a point near the bottom of the hill, such virtual increase being due to excess tractive power over that needed to haul the train at the minimum speed or the virtual increase due to the train being on a grade less than that for which the engine is loaded for the minimum speed. When by such means the velocity of the train has been increased above the minimum speed its stored up energy may be used to raise it on a grade greater in per cent than that for which the engine is loaded. If the velocity at the foot of the grade is sufficient the train will reach the summit of the grade without reducing the speed below the minimum, and the grade may then be termed a velocity or momentum grade for that particular train.

In the discussion of acceleration the following deduction was made, "If the force be known and it is desired to determine the distance required to increase the velocity from S_1 to S_2 miles per hour,"

$$l = 70 \frac{W}{P} (S_2^2 - S_1^2) \qquad \text{(B)}$$

Assume for example that an engine is loaded for a maintained speed of ten miles per hour on a one per cent grade. The full power of the engine must then be exerted to maintain this speed on the one per cent grade. But if a stretch of level track be encountered the virtual increase in tractive effort at once becomes 20 pounds per ton or the acceleration of the train becomes the same as it would be if the engine was loaded for a maintained speed of ten miles per hour on a level grade and a descending grade of one per cent was encountered.

By use of the equation above we only need to know the additional increase in virtual tractive effort to determine the distance required for any change in velocity. As the train resistance and engine tractive power are constantly changing with changes in speed the force P available for acceleration can never be constant, hence equation (E) should be used and the distance traversed for successive changes of speed of one mile per hour calculated. The sum of the distance for each one mile per hour change of speed will then give as accurately as it is practicable the total distance traversed between the desired speed limits. Equation (E) as previously given is --

$$1 = 70 \frac{W}{P}(2 S_1 + 1) \qquad (E)$$

To determine the value of P in equation (E) there must first be determined the available power in pounds per ton, derived by subtracting from the total drawbar pull the total resistance including train resistance, curve resistance and grade resistance, and dividing the remainder by the gross tonnage back of tender. As all of the internal resistances of the locomotive are taken into account in deriving the drawbar pull at various speeds no account need be taken of the engine in making the calculations. If the train be on a descending grade the virtual drawbar pull will of course be added, that is the virtual draw bar pull or increase in tractive effort due to the grade acceleration. The value of P taken as an average of the initial and final velocity of one mile per hour intervals will be correct to several decimal places, hence we may assume for all practical purposes that P is a constant between limits of one mile per hour change in velocity, and is the average value determined from the initial and final velocities for each one mile per hour change.

The use of either equation (B) or (E) in extended calculations requires a great amount of work which may be eliminated to a large extent by interchanging the speed with velocity head, the latter figure being readily selected from Table III for any given speed.

The equation for velocity head was determined as--

$$h = .035\ S^2 \quad \text{or}$$

$$S^2 = \frac{h}{.035}$$

We may then substitute $\frac{h_2}{.035}$ for S_2^2. and $\frac{h_1}{.035}$ for S_1^2 in equation (B), which will then take the form ---

$$l = 2000 \frac{W}{P} (h_2 - h_1)$$

When P is expressed in pounds per ton W will become unity, and the equation may be written ---

$$l = \frac{2000}{P} (h_2 - h_1) \quad \text{or}$$

$$l = \frac{h_2 - h_1}{\frac{P}{2000}}$$

The term $h_2 - h_1$ is equal to the difference in velocity heads and P/2000 is equal to total resistance per ton, or in other words, l expressed in terms of 100 foot stations, will equal the difference in velocity heads divided by the grade of acceleration or the virtual excess tractive power in pounds per ton expressed as the grade of acceleration or retardation. In case of retardation the equation remains the same with a minus sign as prefix.

Table VIII was derived in accordance with the preceeding suggestion. The first column shows the speed. The second column gives the corresponding velocity head taken from Table III. The third column gives the difference in velocity heads for changes of speed of one mile per hour. Column four shows the available drawbar pull in pounds per ton of train back of tender for speeds shown in column one. Column five gives the train resistance in pounds per ton at the different speeds on the basis of cars of twenty tons average weight. The reason for using twenty ton cars is that the resistance is greater per ton in twenty ton cars than in heavier cars, and in laying out velocity grades the most unfavorable conditions must be assumed in order that any engine may handle the tonnage for which it is loaded, whether it be made up of light or heavy cars. Column six gives the excess drawbar pull on level track over and above what is required to maintain the speed shown in column one. Column seven shows the average grade of acceleration or retardation or the mean equivalent grade due to the excess drawbar pull given in column six. To find the distance required for any acceleration of speed or retardation of speed, we then have only to take the algebraic sum of the mean equivalent grade and any other grade on which the train may be operating and divide such sum into the difference in velocity heads. The result is expressed as distance in 100-foot stations.

In making up the table the drawbar pull at various speeds was selected from engines #727 to #741 on account of the fact that these engines show the greatest decrease in drawbar pull with increase in speed of any of the Frisco road locomotives, and therefore represent the most unfavorable class of engines which may be expected to operate over any track. It may be safely assumed that any grade which may be operated as a velocity or momentum grade with 20-ton cars and these engines may be operated by any other combination of cars and engines in use on the Frisco Lines at the present or any future date, as the tendency is to increase the weight of cars and the use of superheated steam is undoubtedly increasing the efficiency of engines at high speeds.

The different conditions of loading given should cover most cases of the ruling grades which may be established in grade reduction work, except on very heavy grade country. Special cases requiring additional tabulation can easily be worked out from the information already given.

Some objection has been made to the use of velocity grades by reason of the fact that stops may necessarily be made where in laying out the original profile they were not anticipated, and it would seem well to use the recommendation already made, that these grades should only be laid out on well established lines where the stations and stopping points have been well fixed, or else should only be used where no great expense will be required in case it is desired to eliminate them in the future. For as Wellington says, "when once established no further liberties may be taken without spoiling the entire calculations."

It is recommended further that in laying out or determining such grades a stop be figured at each station, or water tank or passing track, or other place where such is likely to occur as far as can be foretold. It is also recommended that in re-established grade lines, level or as nearly level as possible grades be used at stopping points, to facilitate the starting in either direction, and that these level grades be extended as far as possible at each end of passing track for the same reason.

Table IX is a tabulation of the distances traveled in accelerating speed on various grades with the locomotive drifting. The resistances for 20-ton cars are used, but the assumption is made that the locomotive will gain velocity at the same rate as the cars. Actually this will not be true, as the total resistance in the engine per ton of weight will be somewhat greater. The effect in the calculations will be to show a greater acceleration than actually occurs. As the table will only be used to determine on what portion of a descending grade the locomotive may be allowed to drift, the error is immaterial.

As an example of the application of the figures given in Table VIII, there is given a profile (Fig. G) representing a typical grade line to be found in the Ozark mountain country.

Suppose for exa~ple that the 1.5 per cent grades as shown on the profile are the only grades greater than a one per cent on the remainder of the division, and we wish to know whether the grades shown can be operted as velocity grades with an engine hauling its maximum load at ten miles per hour maintained sp ed on the otherwise ruling grade of one per cent.

From sheet one and two of Table VIII corresponding to the loading given above, we may study the behavior of the train at any point on the profile. Assume as recommended that the train has made a stop at Jonesville Depot, station 100 plus 00 on profile. We first find 1000 feet of level grade. Referring to the level grade column in the table, we find at station 110 the train is moving at a speed of 16.1 miles per hour, and has a velocity head of practically 9.00 feet. The train then enters 1000 feet of plus .5 per cent grade. From the plus .5 per cent grade co column on sheet two, we find by interpolatung between 17 and 18 miles per hour that the speed at station 120 has become 17.7 miles per hour. The next grade is evidently an accelerating grade, but we find the first 1000 feet is on a four degree curve. From Table II it is found a four degree curve increases the resistance the same as a plus .16 per cent grade, so that in effect the grade from station 120 to 130 is a minus .84 per cent grade. By interpolation in the minus 0.8 and 0.9 grade columns on sheet one, it is found the speed will be about 26.1 miles per hour at station 130. Carrying out the calculations on each grade and making the necessary corrections to grade for curvature, it is found that at station 140 the speed will be in excess of the allowable speed of 30 miles per hour. Brakes must then be used to keep the speed to 30 miles per hour until station 140 is reached. In practice steam should be shut off at station 120 and the speed accelerated with the locomotive drifting. From Table IX the distance required to gain a velocity of 30 miles per hour may be determined. As the train will evidently lose speed between stations 140 and 145 with the locomotive drifting, sufficient steam will have to be applied to keep the speed at thirty miles per hour by the time station 145 is reached. The one per cent grade from station 145 to 155 will evidently be a retarding grade for a speed of thirty miles per hour, as the locomotive is loaded for a maintained speed of only ten miles per hour on a one per cent adverse grade. From sheet two we find the speed at station 155 will have been reduced to practically 25 miles per hour. The two degree curve on the next plus 0.4 grade will make the resistance equal to a plus .48 per cent grade. At station 170 we then find that the speed has been further reduced and is practically 22 miles per hour. At station 190 the speed will have been accelerated on the level grade to practically 26 miles per hour. At station 200 at the end of the 1000 foot adverse plus 1.5 per cent grade, or plus 1.54 correcting for the resistance of the one degree curve, the speed will have been reduced to 19 miles per hour. At station 205 speed will be accelerated to 27 miles per hour, and as there is 2000 feet of accelerating minus 1.5 per cent grade following station 205 it is evident steam will be shut off and brakes used to keep the speed to not exceed 30 miles per hour. Enough steam will then be used to keep the speed at 30 miles per hour to station 235 where 3000 feet of adverse plus 1.5 per cent grade is encountered. From sheet two we find that at station 264 plus 30 the speed will have been reduced to ten miles per hour, the minimum permissable speed. The 1.5 per cent grade can only be operated as a velocity grade to station 264 plus 30 then, and if we wish to haul the load specified we must start reducing at that point to a plus 1.0 per cent grade. At station 270 we find a five degree curve to station 285. We may lay a grade from station 264 plus 30 to the summit of the hill as follows:- Station 264 plus 30 to station 270, a plus 1.0 per cent grade; station 270 to 285, a plus 0.8 per cent grade, or the plus 0.8 per cent grade may be extended past station 285 and connected with a vertical curve to the accelerating minus 1.5 per cent grade starting at station 290.

By study of the saving in train miles which can be made by hauling the full tonnage over the summit at station 285, it may be readily determined whether the reduction in grade as indicated will be profitable.

If the physical conditions will warrant, it will probably be cheaper to raise the sag between stations 225 and 235 to such a point that the summit may be reached at station 285 without the speed being reduced below ten miles per hour. By experiment it may be shown that by raising the level grade between stations 225 and 235, 15 feet, the summit at station 285 will be reached with a speed of a little over ten miles per hour. A rough estimate will probably show that it will be more economical to reduce the summit than to reduce the sag, or possibly the same result may be accomplished by combining the two reductions.

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